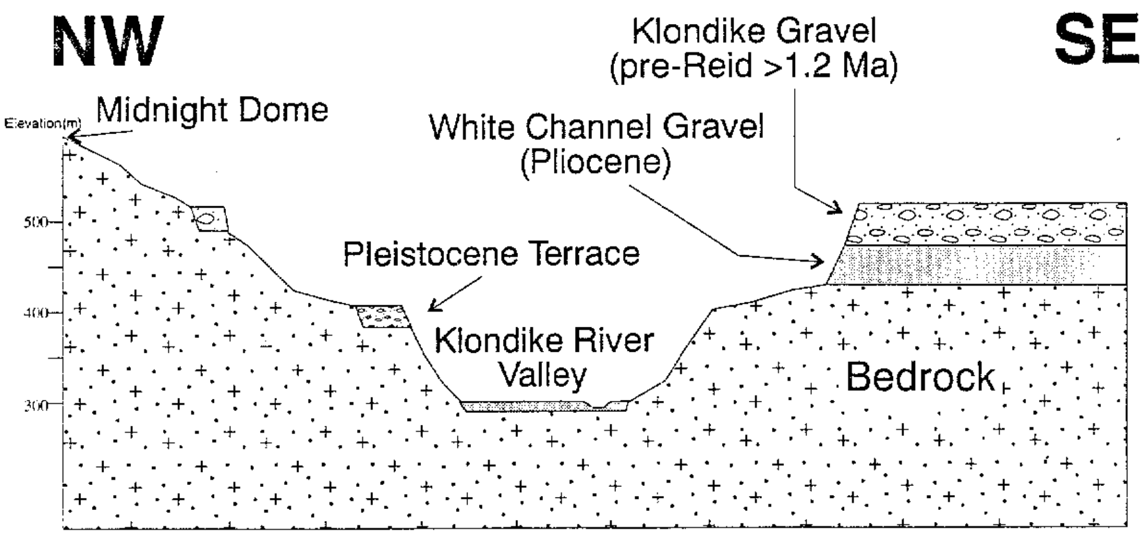
Indian and Northern Affairs Canada
Affaires indiennes et du Nord Canada

Exploration and Geological Services Division, Yukon Region

YUKON QUATERNARY GEOLOGY



Volume 1

1996

Canada

Available from:

Exploration and Geological Services Division
Indian and Northern Affairs Canada
#345-300 Main St.
Whitehorse, Yukon
Canada Y1A 2B5

Published under the authority of the
Honourable Ronald A. Irwin, P.C., M.P.,
Minister of Indian Affairs and
Northern Development
Ottawa, 1996

QS-Y112-000-EF-A1
Catalogue No. R72-257/1-1996E
ISBN 0-662-24415-X

Cover: *Terrace gravels along the Klondike River near Dawson City contain economic quantities of placer gold. Paleomagnetic and sedimentological evidence suggests that the pay unit was deposited prior to a previously undocumented pre-Reid glaciation which deposited the upper glaciofluvial unit. Further details may be found in Froese and Hein, this volume.*

Recommended Citation:
LeBarge, W.P. (ed.), 1996. Yukon Quaternary Geology Volume 1, Exploration and Geological Services Division , Indian and Northern Affairs Canada, Yukon Region, 84 p.

Indian and Northern Affairs Canada | Affaires indiennes et du Nord Canada

EXPLORATION AND GEOLOGICAL SERVICES DIVISION
YUKON REGION

YUKON QUATERNARY GEOLOGY
VOLUME 1
1996

PREFACE

These Quaternary research papers summarize the recent work of Quaternary scientists working in various areas of the Yukon. They are based on studies by government geologists, graduate theses and doctoral dissertations. This volume is the first in a series of publications which will document Quaternary research being done in Yukon in the fields of surficial geology, placer geology, glacial history and geomorphology.

These studies could not have been completed without the cooperation and support of local prospectors, placer miners and mining companies, and this publication will serve as a sign of our appreciation to them for their assistance. We hope the publication will assist in the discovery and development of new placer resources, and that it will also serve as a valuable information source for those interested in the environmental sciences.

Thanks are due to Bill LeBarge for his inspiration and dedication to this project as author and editor, and to the other authors for their valuable contributions.

T.J. Bremner
Chief Geologist
Exploration and Geological Services Division
Northern Affairs Program
Yukon Region

PRÉFACE

Ces rapports d'études sur le Quaternaire sont le résultat de recherches effectuées récemment par des spécialistes de cette période dans diverses régions du Yukon. Ils sont basés sur des études réalisées par des géologues de l'administration publique, de même que sur des thèses universitaires et des mémoires de doctorat. Le présent volume est le premier d'une série d'ouvrages qui feront état des recherches sur l'ère quaternaire qui se déroulent au Yukon dans les domaines de la géologie de subsurface, de la géologie placérienne et de l'histoire et la géomorphologie des formations glaciaires.

Ces études n'auraient pu être menées à terme sans la collaboration et l'appui des prospecteurs, exploitants de placers et compagnies minières de la région; cet ouvrage est un gage de notre reconnaissance. Nous espérons que ce document contribuera à la découverte et à l'exploitation de nouvelles ressources placériennes et qu'il sera une source d'information importante pour les personnes qui s'intéressent aux sciences de l'environnement.

Merci à Bill LeBarge pour son inspiration et son dévouement, à la fois en tant qu'auteur et rédacteur en chef, ainsi qu'aux autres auteurs pour leur précieuse contribution.

T.J. Bremner
Géologue en chef
Division des services géologiques et d'exploration
Programme des Affaires du Nord
Région du Yukon

Table of Contents

PLACER DEPOSITS OF THE YUKON: OVERVIEW AND POTENTIAL FOR NEW DISCOVERIES

William P. LeBarge[1]

LeBarge, W.P. 1996a. Placer Deposits of the Yukon: Overview and Potential for New Discoveries, *In*: LeBarge W.P. (ed.), 1996. Yukon Quaternary Geology Volume 1, Exploration and Geological Services Division, Northern Affairs Program, Yukon Region, p. 1-12.

Abstract

Historic placer mining areas in Yukon can be grouped into ten areas: Klondike; Sixtymile; Fortymile; Clear Creek; Moosehorn Range; Stewart River; Clear Creek; Mayo; Dawson Range and Livingstone Creek. Each area has its own geomorphic setting and depositional history which is related to its glacial history. Several Quaternary glacial advances have been described in Yukon, and these are generally divided into three episodes, commonly known as the pre-Reid, Reid and McConnell, in order of oldest to most recent.

Placer deposits in the unglaciated Klondike, Sixtymile, Fortymile and Moosehorn drainages occur in valley-bottoms, alluvial fans, in gulch gravels and as high level terraces. Placer deposits in glaciated areas occur in variably reworked and buried valley-bottom, bench and gulch settings, in auriferous glacial till and glaciofluvial gravels, and in non-glacial gravels which were deposited on top of glacial drift.

Targets for new placer deposits in unglaciated areas include drainages such as Stewart, North Ladue and Yukon rivers which lie outside of the pre-Reid glacial limits. These deposits may occur in abandoned channels, oxbows and point bars, high level terraces, and in tributary gulch and valley bottom placers.

Within glaciated areas, placer deposits may be discovered buried in valleys beneath terraces of pre-Reid glacial drift along the margins of the pre-Reid glacial limit. Mineable placer deposits may also have formed on top of pre-Reid glacial drift and may be buried in valleys beneath Reid-age non-glacial alluvium. Prospective areas of this type are drainages which are near lode gold deposits in the Clear Creek area and in drainages near felsic volcanics in the Dawson Range. At the limits of both the Reid and McConnell glaciations, auriferous pre-glacial or interglacial gravel can often be buried by glacial and glaciofluvial deposits. Low-grade auriferous glaciofluvial gravel can also be derived from the reworking of pre-glacial gold-bearing gravel. Prospective areas for these types of placer deposits are the South McQuesten River valley and the creeks draining the Ruby Range on the east side of Kluane Lake. Within the McConnell glacial limits, placer deposits may be found in valleys oriented obliquely to the paleoflow direction of the glacial ice. Economic to sub-economic placers may also be found along meltwater channels within the McConnell ice limit. Prospective areas of this type of deposit are the drainages which lie to the north of Livingstone placer camp.

The possibilities for new placer mining areas within glaciated areas must be investigated, and new placer gold reserves will undoubtedly be found within these areas. These potential gold deposits may be explored by techniques such as surficial mapping, airphoto interpretation and bulk sampling of potential gold-bearing units.

[1] Exploration and Geological Services Division, Northern Affairs Program, Indian and Northern Affairs Canada, #345-300 Main St., Whitehorse, Yukon Y1A 2B5.

Introduction

Although the Yukon has been glaciated at least four times, much of central Yukon escaped the effects of the Cordilleran ice sheets, which generally moved into the Yukon from southeast to northwest. The historically rich Klondike placer deposits in central Yukon were preserved from the scouring effects of the ice sheets which affected southern Yukon.

Placer deposits in the Yukon occur in both glaciated and unglaciated areas, although the vast majority of placer gold mined has been derived from the unglaciated areas. Aside from these major geographic subdivisions, placer deposits occur within a number of different stratigraphic and geomorphic settings.

The presence of economic placer concentrations of gold in any one geographic area depends on a number of variables, such as how recently the area has been glaciated, the age of the deposits, the number of changes in drainage or base level, and of course the presence, absence and nature of lode gold in the local bedrock.

The potential for new placer discoveries in the Yukon remains high, as past exploration for placer deposits has focused mainly on traditional (unglaciated) areas and only the most accessible drainages have seen extensive examination and testing. The search for new placer deposits, in the presence of diminishing reserves in traditional areas, is important in order for the placer mining industry to survive. By expanding our present knowledge of placer deposits and applying it to other areas we may be able to discover new sources of placer gold in settings where the potential has not yet been fully realized.

Previous Work

Previous Yukon researchers in placer and glacial geology include R.G. McConnell (1905, 1907), H.S. Bostock (1948, 1966), O.L. Hughes (1969, 1987; Hughes et al. 1969, 1972, 1989), A. Duk-Rodkin (Duk-Rodkin et al., 1995), L. Jackson (1993), T. Giles (1993), F.J. Hein (Morison and Hein, 1987), S.R. Morison (1983, 1985, 1989), R.L. Hughes (1986), and E. Fuller (1994, 1995). R.G. McConnell first described the gold-rich White Channel Gravels in the Klondike area, while H.S. Bostock originally defined multiple glacial episodes in central Yukon. O.L. Hughes described detailed glacial limits which expanded upon Bostock's research. Several surficial geology mappers have maintained an interest in placer geology including Dr. A. Duk-Rodkin and Dr. L. Jackson of the Terrain Sciences Division of the Geological Survey of Canada. These researchers have improved our understanding of glacial limits and processes in the Yukon over the last several years. In addition, several graduate theses have been completed documenting Yukon placer deposits, including those of S.R. Morison, R.L. Hughes and W.P. LeBarge, all of which were supervised by Dr. F.J. Hein (University of Calgary). Government personnel involved in the recent studies of Yukon placer deposits include S.R. Morison and W.P. LeBarge (Mineral Resources Directorate, Northern Affairs Program) and E. Fuller (Canada/Yukon Geoscience Office). This summary paper draws somewhat loosely upon the work of these scientists and apologies are given for the lack of exact specific references to their excellent work.

Glacial History of Yukon

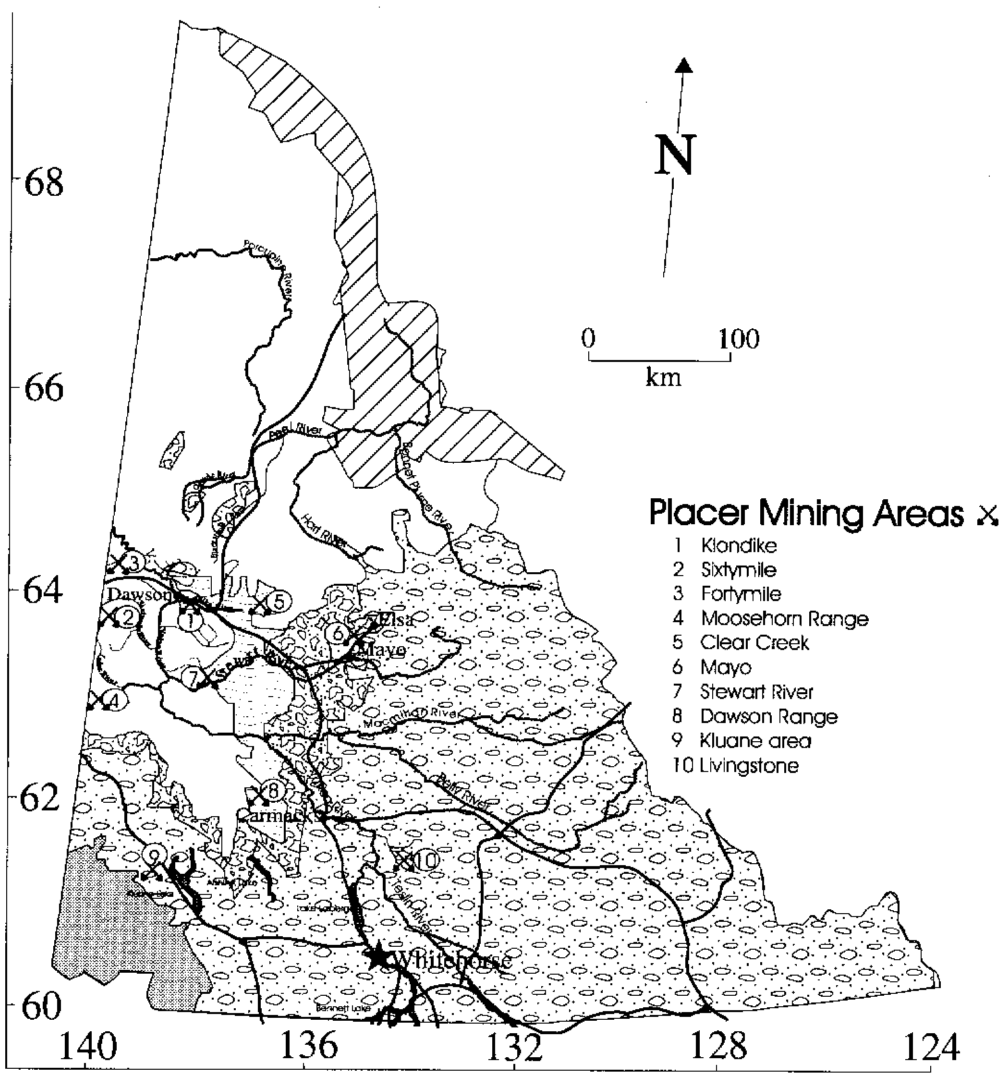
It is important to understand something about the glacial history of a prospective placer area, as glaciations generally disperse, rework and bury placer deposits. Several glacial advances have been described in Yukon, and these are generally divided into three episodes, commonly known as the pre-Reid, Reid and McConnell, in order of oldest to most recent (Figure 1). Many Quaternary researchers have used soil characteristics to differentiate between these glacial deposits of different ages (Foscolos et al., 1977; Smith et al., 1986; Tarnocai, 1987)

The pre-Reid glaciations are believed to be the oldest and most extensive Cordilleran ice advance (Bostock, 1966; Hughes, 1987), reaching into the Yukon as far as the Dawson area, and in fact within the Tintina Trench the ice probably extended past Dawson City (Duk-Rodkin and Froese, 1995). Some glaciofluvial outwash gravels (locally known as the 'Klondike Wash' or 'Klondike Gravels') from the pre-Reid ice sheet overlie the White Channel Gravels along Hunker and Bonanza Creeks in the Klondike (Naldrett, 1981; Hughes et al., 1972).

Recent research (Duk-Rodkin et al., 1995) has indicated the possibility of four or more separate glaciations occurring prior to the Reid glaciation, although because of limited preservation and exposure and the difficulty in correlation these old glacial advances are often collectively referred to by researchers as the pre-Reid.

Glacial features of the pre-Reid advances are very subdued and deposits are difficult to recognize on airphotos, often having been reworked by subsequent glacial and fluvial processes and covered by colluvium (slope deposits).

The Reid glaciation was less extensive than the earlier pre-Reid glaciations and more extensive than the later McConnell glaciation. Recent age dating of



Unglaciated Terrain

Undifferentiated nonglacial deposits

Glaciated Terrain

McConnell glacial deposits

Hungry Creek or Buckland glacial deposits

Reid glacial deposits

Icefield glaciers

pre-Reid glacial deposits

Figure 1: Glacial Limits and Placer Mining Areas (modified after Hughes, 1987)

Sheep Creek tephra, a volcanic ash which overlies Reid glacial drift in the Ash Bend site, Stewart River, are in the range of 200 Ka (Berger, 1994; Ward, 1993). Thus the Reid ice began retreating from its maximum extent prior to that time. Deposits of the Reid glaciation outside of the McConnell glacial limits are relatively unchanged and are fairly easily recognized on airphotos.

The McConnell glaciation was the least extensive of all Cordilleran glaciations, as well as the most recent. The onset of McConnell glaciation has been recently dated as less than 29 Ka. and dates for the retreat of McConnell ice are in the range of 10.3 Ka. (Hughes et al., 1989). Deposits of McConnell glacial drift are easily recognizable on airphotos and on the ground, having been only minimally reworked by fluvial and colluvial processes.

Placer Gold Production

Most historic mining areas in the Yukon, such as the Klondike and Sixtymile districts, lie beyond the limit of Pleistocene Cordilleran glaciations. Although the majority of past and current production of placer gold has been derived from these unglaciated areas, reserves in these areas are slowly being depleted. Gold production in recent years has been variable, declining from a modern day production record of 169,345 crude ounces in 1989 to a recent low of 101,061 ounces in 1992. Production has rebounded by approximately 8% per year since, reaching 127,143 crude ounces in 1995 (van Kalsbeek, 1996). Annual direct employment in the placer mining industry totals 700 to 800 people in an average of 200 operations, most of which are small family-owned and operated mines.

Placer Mining Areas in Yukon

Placer mining areas in Yukon are generally divided into two categories: deposits in unglaciated areas and deposits in glaciated areas. There are ten areas with current mining activity: Klondike; Sixtymile, Fortymile; Clear Creek; Moosehorn Range; Stewart River and its tributaries; Clear Creek; Mayo; Dawson Range; and Livingstone Creek area.

Placer Deposits in Unglaciated Areas

Klondike/Sixtymile/Fortymile

Placer deposits in these areas share a number of characteristics including glacial history, type of lode gold source, overall weathering history and the main geomorphic setting of the placers. Placer deposits in these unglaciated areas occur in valley-bottoms, alluvial fans, in gulch gravels and as intermediate level terraces - e.g. Klondike Valley gravel terraces (Froese and Hein, this volume) to high level gravel terraces - e.g. White Channel Gravels (Morison, 1985; Morison and Hein, 1987). There are several local point sources of gold, mainly quartz veins in Paleozoic metamorphic rocks (Klondike Schist and Nasina series) although for some areas the lode source of many of the placer gold deposits remains problematic (Knight et al., 1994). Since these areas are unglaciated, alluvial sediments have undergone an extensive period of weathering and fluvial reworking, essentially since the Tertiary period. This has allowed a continuing cycle of uplift and erosion to concentrate and reconcentrate placers in rich pay streaks in valley bottoms, valley side alluvial fans and bedrock terraces (Figure 2).

Figure 2: The late Tertiary age White Channel Gravels in the Klondike area are terrace deposits which represent an ancient non-glacial fluvial system. Placer gold in these rich gravels was reworked to form the world-class placer deposits which were found along the valleys of Bonanza, Eldorado and Hunker Creeks.

Moosehorn Range

The placer gold deposits of the Moosehorn Range have undergone a similar weathering history as the placer deposits of the Klondike and Sixtymile areas. The lode gold source has been identified as the high-grade gold-quartz veins which cut the granodiorite batholith on the ridge above the creeks. The placer deposits consist of gulch gravels in the higher reaches and alluvial fans in the lower reaches. The gulch gravels have discrete pay streaks while the alluvial fans have more scattered and irregular pay streaks, except at their apex where a more continuous placer accumulation can be expected.

Stewart River

The Stewart River crosses an area from the McConnell glacial limit, to the Reid glacial limit, to the pre-Reid glacial limit, into unglaciated terrain. Throughout these reaches placer gold occurs on active point and channel bars along the current course of the river, and along abandoned channels and oxbows in areas where the stream course has shifted. This placer gold has mainly been transported during flood events from a number of dispersed sources of gold, from tributaries such as Clear Creek and McQuesten River and from glaciofluvial sediments on bedrock terraces adjacent to the Stewart River. Tributaries of the Stewart river in the unglaciated areas contain placer gold deposits along valley-bottoms, in narrow gulches, within alluvial fans and on intermediate level bedrock terraces (Fuller, 1994; 1995).

Placer Deposits in Glaciated Areas

Clear Creek

The Clear Creek area lies within the pre-Reid glacial limit, just outside the limit of the major Reid valley glaciation but including areas which may have been subject to alpine glaciers during the Reid episode. Surficial deposits include Tertiary (Pliocene?) gravels similar to the White Channel deposits, pre-Reid glacial drift which has covered the Tertiary gravels, Reid alpine drift, Quaternary valley-bottom and buried placers, and colluvial deposits (Morison, 1983). The lode source of gold is probably related to the numerous intrusions in the area and associated gold-quartz veins.

Mayo Area

The placer gold deposits in the Mayo area lie at the margins of both the Reid and the McConnell glaciations, which depending on topography and elevation may be only be a few kilometres apart.

The Dublin Gulch/Haggart Creek area lies within the Reid glacial limits. Placer deposits consist of valley bottom, gulch and colluvial sediments which have formed since the Reid glaciation, since the McConnell ice did not reach into this area.

Mayo Lake tributaries, including Duncan Creek and the surrounding areas lie on the edge of the McConnell glaciation but entirely within the Reid glacial limits. Most of the Mayo Lake placer deposits lie at the apex of fan-deltas which have built into the lake since the McConnell episode (Figure 3).

Figure 3: Economic placer gold deposits in the Mayo area have been mined at the apex of fan-deltas which have built into Mayo Lake. Most of these fans such as this one on Anderson Creek have formed since the end of the last glaciation.

Some of the placer deposits in the Duncan Creek area consist of gold-bearing glaciofluvial gravels and glacial till of probable Reid age. These formed by scouring and reconcentrating gold from a number of sources including pre-existing placers and bedrock. Valley-bottom, alluvial fan and gulch placers also incorporate reworked gold from pre-existing non-glacial gravels, glacial till and glaciofluvial gravels.

The bedrock source of gold in the area is likely related to intrusions and quartz veins which cut the local Paleozoic schist and quartzite.

Kluane area

Kluane area placer deposits generally occur in two settings which are geographically divided by Kluane Lake. The Kluane area has been glaciated several times, with each successive glaciation being less extensive than the previous one. The east side of Kluane Lake (e.g. Gladstone Creek) was last covered by glacial ice during the second most recent glaciation (Reid equivalent), when valley glaciers originating in the St. Elias Range formed piedmont lobes which extended across Kluane Lake (Mueller, 1967; Hughes et al., 1972).

Placer deposits in the Gladstone Creek area consist of auriferous glaciofluvial and recent stream gravels which have reconcentrated gold above bedrock on top of glacial till and glacial lake sediments. Part of this reconcentration may be the result of meltwater action at the end of the last local glaciation, and part may be due to fluvial reworking and reconcentration since that time. The placer gold is likely derived from a number of sources in bedrock and pre-glacial or interglacial gravels.

Burwash Creek and nearby creeks were affected by the most recent ice advance which was confined to the west side of Kluane Lake. Prior to the latest glacial episode the Slims river actually drained in the opposite direction (southward) into the Kaskawush River (Bostock, 1969). Glacial diversions of streams by ice-damming and the subsequent release of meltwaters resulted in a large amount of fluvial downcutting (in many cases to bedrock) and caused reworking of sediments when streams were forced to adjust to new base levels and cut new channels. Recent fluvial activity, most active during flood stages, continues to concentrate placer gold in gravel bars along and adjacent to the present stream channel.

Mt. Freegold/Mt. Nansen

Placer deposits of the Dawson Range lie within the pre-Reid glacial limits. Gold has been found in pre-Reid glacial till and glaciofluvial gravels, as well as in non-glacial gravels which were deposited after and on top of pre-Reid glacial and glaciofluvial deposits. Gold was preserved in the glacial material because the pre-Reid glaciation that affected the area was of an alpine nature, which resulted in only limited dispersion of pre-existing fluvial placers. These gold-bearing sediments were then incorporated into the glacial till (LeBarge, 1993; 1995). This type of process has also been documented in the Cariboo placer district in British Columbia (Eyles and Kocsis, 1989). Normal fluvial processes have subsequently concentrated gold above bedrock on top of the glacial till which acted as a "false bedrock" which was resistant to downcutting. The gold is likely derived from lode sources within the numerous felsic intrusions and related vein systems in the area (Carlson, 1987; Jackson, 1993).

Livingstone/South Big Salmon Area

Placer deposits in the Livingstone placer camp lie well within the McConnell glacial limit, the most recent glacial advance. Auriferous interglacial gravels formed between the Reid and the McConnell glaciations occupy east-west trending valleys which are transverse to the direction of ice movement. These placers were buried by several metres of glacial drift (Figure 4), which protected them from the erosive action of the ice which later scoured the ridges as the ice sheet moved northwestward (Levson, 1992). The gravels were later re-exposed by a large amount of fluvial downcutting at the end of the glaciation and during a period of post-glacial fluvial reworking. The source of gold in the Livingstone area is most likely tellurides and free gold in small quartz veins which cross-cut local graphite schist bedrock (Stroink and Friedrich, 1992).

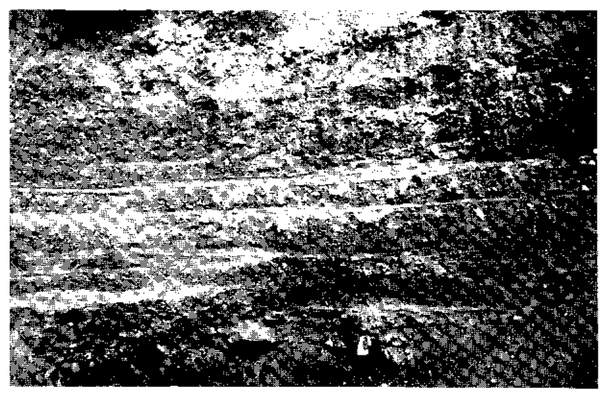


Figure 4: Thick McConnell glacial drift has covered interglacial gold-bearing gravels in the Livingstone Creek area. This deposit on Little Violet Creek was partially reworked and diluted by glaciofluvial gravels prior to the infilling of the valley which protected it from erosion by advancing glacial ice.

Whitehorse South (Moosebrook, Pennycook) and Quiet Lake (Sidney/Iron Creek) Areas

The placer gold-bearing gravels of Quiet Lake and Whitehorse South areas (Moosebrook, Pennycook, Sidney, and Iron creeks) lie completely within the McConnell glacial limits, and are generally poorly understood as little scientific work has been done in the area. They may be similar in genesis to the placer

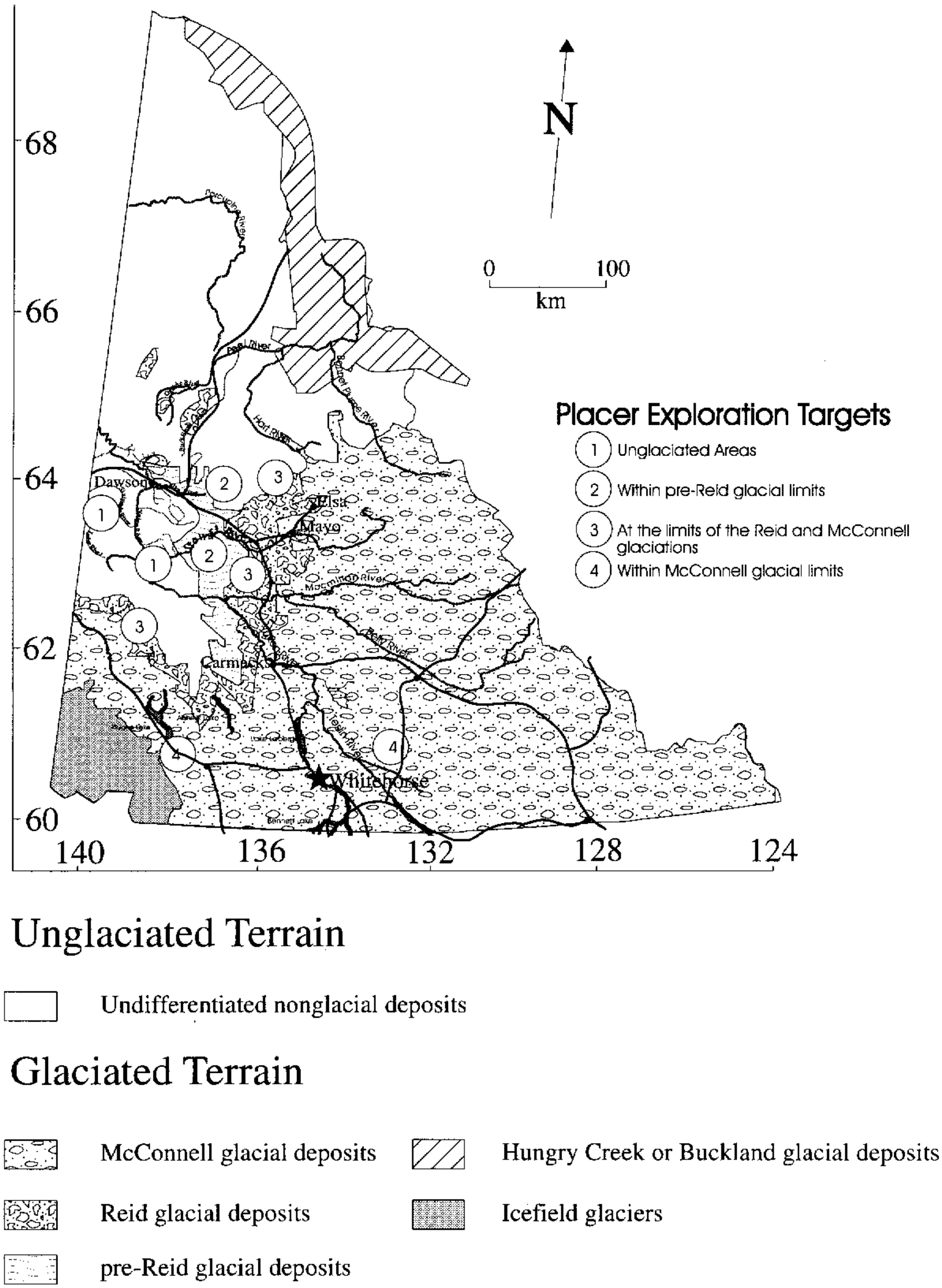


Figure 5: Glacial Limits and Placer Exploration Targets (modified after Hughes, 1987)

deposits on Livingstone Creek, where auriferous interglacial gravels formed during the long period of fluvial action between the Reid and the McConnell glaciations. Limited airphoto interpretation shows that the placers were not very well protected from the McConnell ice sheet, as glacial deposits fill the major valleys and tributaries. Sidney Creek was temporarily diverted to the west by glacial ice which blocked its confluence with Iron Creek. The placer deposits must therefore have formed from the reconcentration of gold from dispersed sources in the glacial material and the bedrock. This would have been accomplished by the action of glaciofluvial meltwaters at the end of the last glaciation, and subsequent fluvial action.

Placer Exploration Tools

Several points are evident from the preceding summary of the Yukon placer deposits. Primarily, it is obvious that it is necessary to study the glacial history of an area in order to understand how the placer deposit formed. Secondly, it is possible to explore for new placer deposits by describing the types of sediments which are gold-bearing and applying this knowledge to new areas.

Airphoto interpretation and the study of surficial maps, are important placer exploration tools which can indicate the presence of glacial deposits in the area, if there are high level terraces and buried channels or sometimes even if drainage diversions have occurred.

Finally, it is important to sample potential gold-bearing gravel in the prospective new placer area. This can be accomplished by auger or percussion drilling, test pits, and bulk sampling. Small, portable sluice boxes and hand-panning of concentrates can then be used to determine the gold content of the gravel.

Placer Exploration Targets

Unglaciated areas

Figure 5 shows several prospective areas for placer exploration. In unglaciated areas, new placer deposits will be found in hitherto inaccessible areas. Targets in these areas include abandoned channels, oxbows and point bars of major drainages, high level terraces of these major drainages, and gulch and valley bottom placers along tributaries of these major rivers. Prospective areas include the reaches of Stewart, North Ladue and Yukon rivers and their tributaries which lie outside of the pre-Reid glacial limits (Figure 6).

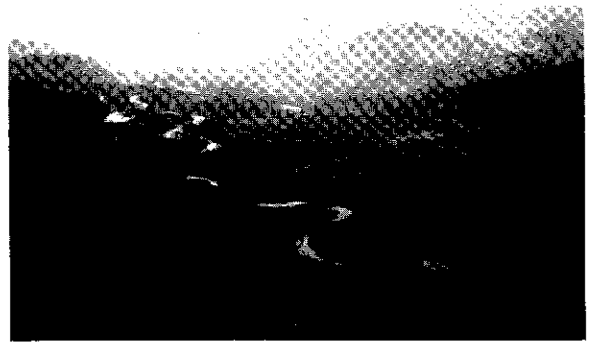


Figure 6: Much of the unglaciated western part of Yukon has had limited exploration due to poor access. Placer gold in known to occur in tributaries to the North Ladue River and further exploration in this area is warranted.

Within the pre-Reid glacial limits

Along the margins of, and just within, the pre-Reid glacial limits, new placer deposits may be discovered in valleys buried beneath terraces of pre-Reid glacial drift. Clear Creek is one example of an area where pre-Reid drift has buried and reworked pre-glacial fluvial placer deposits. Economic placers may also have formed on top of pre-Reid glacial and glaciofluvial deposits, or may be buried in valleys beneath Reid age non-glacial alluvium, such as in the Mt. Nansen area in the Dawson Range. Prospective new areas are drainages known near hardrock gold deposits in the Clear Creek area, (Vancouver, Thoroughfare creeks, McQuesten River and its tributaries) and in creeks which drain areas of felsic intrusive and volcanic rocks in the Dawson Range (e.g., Lonely Creek, Schist Creek).

At the limits of Reid and McConnell glaciations

At the limit of both the Reid and McConnell glaciations, depositional processes tend to be dominant. In this case, auriferous pre-glacial gravel is often buried by glacial and glaciofluvial deposits rather than scoured and dispersed. Low grade auriferous glaciofluvial gravel can also be derived from the reworking of pre-glacial gold-bearing gravel. Prospective areas for placer deposits are the McQuesten and South McQuesten River valleys and their related tributaries and creeks east of Kluane Lake. Economic to sub-economic placers may also be found along meltwater channels at the McConnell ice limit, for example Florence Creek in the Carmacks area.

Within McConnell glacial limits

Inside the McConnell glacial limits, special circumstances were required to form and preserve significant placer deposits. These deposits can be found in protected valleys which are oriented oblique to the direction of flow of the glacial ice. In these valleys the advancing ice sheet is less able to scour and remove the previously-formed (interglacial) placer deposits and the valleys are instead filled with glaciofluvial and glacial sediment. Prospective areas of this type of deposit are the drainages similar to Livingstone placer camp which lie to the north, such as D'Abbadie Creek and Teraktu Creek. Placers in this setting can also be found in valleys where meltwaters and fluvial action have reconcentrated gold from a number of dispersed sources into mineable deposits. One prospective area for this type of deposit is on the eastern flank of the Big Salmon Range, such as Sidney and Iron Creek.

Conclusions

It is evident that historic exploration for Yukon placer deposits has focused on unglaciated areas and easily-accessible drainages. In order for the placer mining industry to continue at present levels, new areas must be found. Potential placer deposits in less-accessible areas must be explored, and the possibilities for new placer gold reserves at the margins of and within glaciated areas must be investigated. New placer gold reserves will undoubtedly be found within these areas. The difficulties in finding these buried, pre-glacial or interglacial channels and prospective new placer gold deposits can be at least partially overcome by the use of more sophisticated exploration techniques, including surficial geological mapping, airphoto interpretation, heavy mineral studies and bulk sampling of potential gold-bearing units.

References

BERGER, G.W. 1994. Age of the Alaska/Yukon Sheep Creek tephra from thermoluminescence dating of bracketing loess at Fairbanks. A bridge of the science between North America and the Russian Far East. Paper presented at the 45th Arctic science conference, 25-27 August, 1994, Anchorage, Alaska-29 August-2 September, 1994, Vladivostok, Russia.

BOSTOCK, H.S. 1948. Physiography of the Canadian Cordillera, with Special Reference to the Area North of the Fifty-fifth Parallel. Geological Survey of Canada Memoir 247 (Report and Map 922 A). 106 p.

BOSTOCK, H.S. 1966. Notes on Glaciation in Central Yukon Territory. Geological Survey of Canada Paper 65-36 (Report, 1 figure and 7 plates). 18 p.

BOSTOCK, H.S. 1969. Kluane Lake, Yukon Territory, its drainage and allied problems. (115G and 115F E). Geological Survey of Canada Paper 69-28 (Report and 8 figures). 19 p.

CARLSON, G.G. 1987. Geology of Mount Nansen (115I 3) and Stoddart Creek (115I 6) Map Areas, Dawson Range, Central Yukon. Exploration and Geological Services Division, Indian and Northern Affairs Canada, Open File 1987-2, 181 pp. with two 1: 30 000 scale maps.

DUK-RODKIN, A., and FROESE, D. 1995. Origin and extent of drift cover, northwestern Canada. Poster presented at the Cordilleran Roundup, Vancouver, British Columbia, February 1995.

DUK-RODKIN, A., BOND, J., JACKSON, L.E. Jr., and BARENDREGHT, R.W. 1995. Mid to Late Cenozoic record of glaciations in the northern Canadian Cordillera. Abstract and poster presented at the Cordilleran Roundup, Vancouver, British Columbia, February 1995.

EYLES, N. and KOCSIS, S.P. 1989. Sedimentological controls on gold in a late Pleistocene glacial placer deposit, Cariboo Mining District, British Columbia, Canada. Sedimentary Geology, v. 65, p. 45-68.

FULLER, E.A. 1994. High level terraces along lower Stewart River and parts of Yukon River. *In*: Yukon Exploration and Geology, 1993, Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p.15-28.

FULLER, E.A., 1995. High level terraces along parts of Yukon River and Sixtymile River. *In*: Yukon Exploration and Geology, 1994, Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p.31-46

FOSCOLOS, A.E., RUTTER, N.W., and HUGHES, O.L. 1977. The use of pedological studies in interpreting the Quaternary history of central Yukon Territory. Geological Survey of Canada Bulletin 271, 48 p.

HUGHES, O.L. 1969. Distribution of open system pingos in central Yukon Territory with respect to glacial limits (Report and 2 figures), 8 p.

HUGHES, O.L. 1987. Quaternary Geology. *In*: Guidebook to Quaternary Research in Yukon, Morison, S.R. and Smith, C.A.S. (eds.) XII INQUA Congress, Ottawa, Canada. National Research Council of Canada, Ottawa, p. 12-16.

HUGHES, O.L., CAMPBELL, R.B., MULLER, J.E., and WHEELER, J.O. 1969. Glacial Limits and Flow Patterns, Yukon Territory, South of 65 Degrees North Latitude. Geological Survey of Canada Paper 68-34 (Report and Map 6-1968). 9 p.

HUGHES, O.L., RAMPTON, V.N. and RUTTER, N.W. 1972. Quaternary Geology and Geomorphology, Southern and Central Yukon (Northern Canada). XXIV International Geological Congress, Field Excursion Guidebook A 11, 59 p.

HUGHES, O.L., RUTTER, N.W., and CLAGUE, J.J. 1989. Chapter 1, Yukon Territory, Quaternary Stratigraphy and History, Cordilleran Ice Sheet. *In*: Fulton, R.J. (ed.) 1989. Quaternary Geology of Canada and Greenland; Geological Survey of Canada, Geology of Canada, No. 1, p. 58-62.

HUGHES, R.L. 1986. Placer Gravels, Sixtymile River Area, Yukon Territory. Unpublished M.Sc. Thesis, University of Alberta, Edmonton, Alberta.

JACKSON, L.E. Jr. 1993. Origin and stratigraphy of Pleistocene gravels in Dawson Range and suggestions for future exploration of gold placers, southwestern Carmacks map area, Yukon Territory. *In*: Current Research, Part A; Geological Survey of Canada, Paper 93-1A, p. 1-10.

KNIGHT, J.B., MORTENSEN, J.K, and MORISON, S.R. 1994. Shape and Composition of Lode and Placer Gold from the Klondike District, Yukon, Canada. Bulletin 3, Exploration and Geological Services Division, Indian and Northern Affairs Canada, Yukon Region, 142p.

LEBARGE, W.P. 1993. Sedimentology of Placer Gravels near Mt. Nansen, Central Yukon Territory. Unpublished M.Sc. Thesis, University of Calgary, Calgary, Alberta, 272 p.

LEBARGE, W.P. 1995. Sedimentology of Placer Gravels near Mt. Nansen, Central Yukon Territory. Bulletin 4, Exploration and Geological Services Division , Indian and Northern Affairs Canada, Yukon Region, 155 p.

LEVSON, V. 1992. The sedimentology of Pleistocene deposits associated with placer gold-bearing gravels in the Livingstone Creek area, Yukon Territory. *In*: Yukon Geology Volume 3, Exploration and Geological Services Division, Northern Affairs Program, Indian and Northern Affairs Canada, p. 99-132.

McCONNELL, R.G. 1905. Report on the Klondike gold fields. Geological Survey of Canada, Annual Report 14, p.B1-B17.

McCONNELL, R.G. 1907. Report on gold values in the Klondike high level gravels. Geological Survey of Canada Publication 979, 34p.

MORISON, S.R. 1983. Placer deposits of Clear Creek drainage basin, 115P, central Yukon. *In*: Yukon Exploration and Geology 1983, Exploration and Geological Services Division, Northern Affairs Program, Yukon Region, p. 88-93.

MORISON, S.R. 1985. Sedimentology of the White Channel placer deposits, Klondike area, west central Yukon. Unpublished M.Sc. Thesis. University of Alberta, Edmonton, Alberta, 149 p.

MORISON, S.R. 1989. Placer deposits in Canada. Chapter 11, Quaternary Resources in Canada. *In*: Fulton, R.J. (ed.) 1989. Quaternary Geology of Canada and Greenland; Geological Survey of Canada, Geology of Canada, No. 1, p. 687-697.

MORISON, S.R. and HEIN, F.J. 1987. Sedimentology of the White Channel Gravels, Yukon Territory: Fluvial deposits of a confined valley. *In*: Recent Developments in fluvial sedimentology - contributions from the Third International Fluvial Sedimentology Conference, F.G. Ethridge, R.M. Flores and M.D. Harvey (eds.). SEPM Special Publication No. 39, p. 205-216.

MUELLER, J.E. 1967. Kluane Lake map area, Yukon Territory. Geological Survey of Canada Memoir 340.

NALDRETT, D.L. 1981. Aspects of the surficial geology and permafrost conditions, Klondike Goldfields and Dawson City, Yukon Territory. Unpublished M.Sc. Thesis, University of Ottawa, Ontario.

SMITH, C.A.S., TARNOCAI, C., and HUGHES, O.L. 1986. Pedological investigations of Pleistocene glacial drift surfaces in the central Yukon. Geographie physique et Quaternaire, vol. XL, no. 1, p. 29-37.

STROINK, L., and FRIEDRICH, G. 1992. Gold-sulphide quartz veins in metamorphic rocks as a possible source for placer gold in the Livingstone Creek area, Yukon Territory, Canada. *In*: Yukon Geology Volume 3, Exploration and Geological Services Division, Northern Affairs Program, Indian and Northern Affairs Canada, p. 87-98.

TARNOCAI, C. 1987. Quaternary soils. *In:* Guide-book to Quaternary Research in Yukon, Morison, S.R. and Smith, C.A.S. (Eds). XII INQUA Congress, Ottawa, Canada. National Research Council of Canada, Ottawa, p.16-21.

VAN KALSBEEK, L. 1996. Yukon Placer Mining Statistics. 1995. Unpublished summary for Placer Mining Section, Yukon, Indian and Northern Affairs Canada.

WARD, B.C. 1993. Quaternary Geology of Glenlyon Map area (105L), Yukon Territory. Unpublished Ph.D. Thesis, University of Alberta. 232 p.

SEDIMENTOLOGY OF A HIGH LEVEL TERRACE PLACER GOLD DEPOSIT, KLONDIKE VALLEY, YUKON

Duane G. Froese[1] and Frances J. Hein[2]

Froese, D.G. and Hein, F.J., 1996. Sedimentology of a high level terrace placer gold deposit, Klondike valley, Yukon. *In*: LeBarge W.P. (ed.), 1996. Yukon Quaternary Geology Volume 1, Exploration and Geological Services Division, Northern Affairs Program, Yukon Region, p. 13-26.

ABSTRACT

Significant economic concentrations of placer gold were first recognized in an intermediate level terrace near Dawson City in the late 1980's. Regional surficial mapping has shown the distribution of many high level terraces of pre-Reid, Reid and McConnell age in central Yukon, but the relationship between economic gold concentration and terraces is not well understood. Sedimentological study of an intermediate level terrace near Dawson City suggests two river types have been dominant: the first, a 'wandering gravel bed river' is characterized by moderate sinuosity, lateral accretion deposits, limited sand facies, and generally fine gravel; the second, 'proximal braided river' is characterized by multiple channels, very thick and crudely imbricate gravel, low bed relief, and a maximum particle size greater than the underlying wandering gravel bed river deposit. The gold-bearing 'wandering gravel bed river' assemblage is typical of present-day conditions with river processes dominated by lateral migration and high gravel transport rates through the system, conducive to heavy mineral concentration during an interglacial period. The 'proximal braided river' is characteristic of nearby glacial ice and rapid sedimentation resulting in poor heavy mineral concentration. The transition from a wandering gravel bed river to a proximal braided river is suggested to mark the onset of a pre-Reid glaciation in the Southern Ogilvie Mountains. The sedimentology of the intermediate terrace gravels suggests a geomorphic model which may be used for exploration of terrace placer deposits in central Yukon with a similar pattern of regional glaciation influencing terrace formation.

[1] Department of Geography, University of Calgary, 2500 University Dr. N.W., Calgary, Alberta T2N 1N4.

[2] Department of Geology and Geophysics, University of Calgary, 2500 University Dr. N.W., Calgary, Alberta T2N 1N4.

Introduction

During the last continental glaciation, approximately 96% of Canada's present land area was ice-covered, based on the limits defined by Dyke and Prest (1987). The largest ice-free areas were parts of the Arctic Islands and central parts of the northern Yukon Territory, with the latter representing about 250 000 km^2 of an estimated 400 000 km^2 total. While more extensive glaciation occurred previously in central Yukon, the limited ice cover of more recent glacial events resulted in a Pleistocene record with well preserved deposits of multiple glacial ages (some older than 1.2 Ma). In contrast, Pleistocene deposits in the rest of Canada mainly record the most extensive late Wisconsin event (<25 ka). Prominent landform remnants of the multiple older events survive in central Yukon as high level terraces of the Stewart, Klondike and Yukon rivers.

Regional mapping of high level terraces along parts of the Stewart and Yukon rivers by Fuller (1994, 1995) outlines the distribution of terraces of pre-Reid, Reid and McConnell age, and the relationship of glacial limits to terrace formation. While placer gold deposits have been discovered in some of the terraces, no attempts have been made to explain mechanisms leading to their formation or preservation. In this study, the sedimentology of a gold-bearing terrace gravel near Dawson City is the focus of research to outline sedimentary controls on placer accumulation, conditions leading to preservation, and prospects for similar deposits in central Yukon.

Regional Setting and glacial history

The Tintina Trench is a late Tertiary graben developed on the late Cretaceous or early Tertiary Tintina Fault, a strike slip fault with at least 450 km of right lateral movement (Tempelman-Kluit, 1980). This northwest trending lineament separates the Klondike Plateau from the Southern Ogilvie Mountains immediately to the north (Figure 1).

The Klondike Plateau in the Dawson area is an uplifted erosional surface of probable Miocene age composed of poly-deformed metamorphic rocks of the Yukon Tanana Terrane (Tempelman-Kluit, 1976, 1980; Mortensen, 1990). Except for a few local cirque glaciers south of the study area in the Dawson Range, the area is essentially unglaciated.

The Southern Ogilvie Mountains, northeast of the Tintina Trench, consist mainly of thrusted sedimentary successions of Proterozoic and Paleozoic age (Green, 1972). Large intrusions form the highest peaks in the Tombstone Range, which forms part of the Southern Ogilvie Mountains, and served as a centre for the development of local ice masses during the Pleistocene.

Bostock (1966) proposed a record of four successively less extensive glaciations in central Yukon, named from oldest to youngest: Nansen, Klaza, Reid and McConnell. Well-preserved moraines and other ice-marginal features mark the extent of McConnell glaciation; similarly, glacial landforms of Reid glaciation, although subdued, can be traced throughout central and southwestern Yukon (Hughes et al., 1969; 1972). Features of Nansen and Klaza age have only been differentiated in the region described by Bostock (1966). Subsequent workers have grouped these events 'pre-Reid'.

In the Southern Ogilvie Mountains north of Dawson, Vernon and Hughes (1966) noted at least three advances of local valley glaciers: oldest, intermediate and last. These events have been correlated on the basis of relative preservation, limited radiocarbon dates, and soil development with the pre-Reid, Reid and McConnell events of the Cordilleran ice sheet (Hughes et al., 1972, 1989; Smith et al., 1986). The main limits of glaciation, taken from Hughes et al., (1969), and Duk-Rodkin and Hughes (1991) are shown in Figure 2. Recent investigators have suggested more than two pre-Reid events: in the Fort Selkirk area, Jackson et al. (1990), present evidence for two pre-Reid events before 790 ka, with the oldest prior to 1.08 Ma; while Duk-Rodkin et al. (1995), have argued for at least five and possibly seven Cordilleran glaciations between central Yukon and western Northwest Territories prior to the Reid event.

Previous Work

McConnell (1905, 1907) divided the gravels of the Klondike area into stream gravel, intermediate terrace gravel, high level river gravel (or Klondike gravel), and White Channel gravel (Figure 3). Hughes et al. (1972) and Milner (1977) updated information covered by McConnell, and noted that the Klondike Gravel corresponded to the earliest glaciation of the region, based on an interfingering relationship between the glacial Klondike gravel and pre-glacial White Channel gravel. Naeser et al. (1982) reported a fission track age of greater than 1.2 Ma from tephra deposited on a terrace incised into Klondike gravel. Morison (1985) and Morison and Hein (1987) conducted a sedimentological study of the pre-glacial White Channel gravel, addressing the nature of sedimentation, relative age, and relationship to placer gold occurrences.

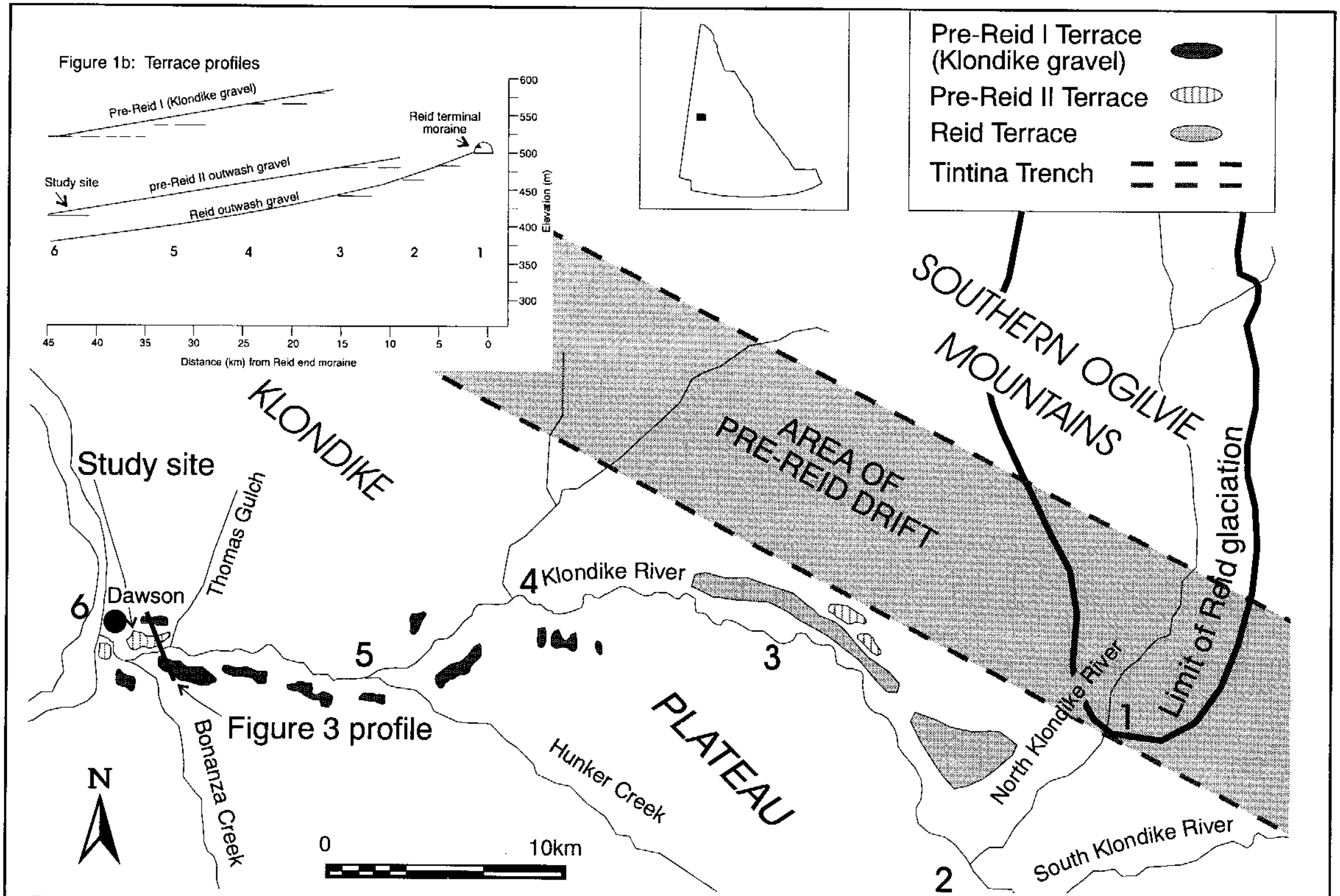


Figure 1: Map of locations mentioned in text and distribution of terraces in the Klondike valley. 1b: Profiles of Klondike valley outwash surfaces, providing a pre-Reid age for the Dome road terrace, based on its occurrence above the Reid outwash profile from the North Klondike valley moraine.

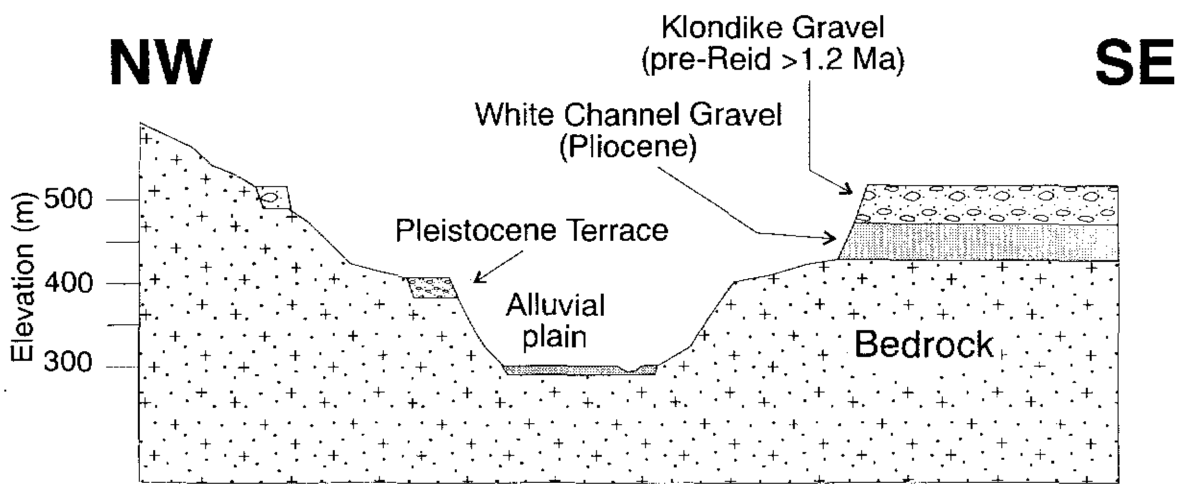


Figure 2: Gravel stratigraphy of Pliocene-Recent deposits in the Klondike area (modified from McConnell, 1907).

Study site and mining history

The first known reference to an intermediate terrace placer in the region is McConnell's (1905) report of gold in 'paying quantities' at 'Acklen's Farm' on the right limit of the Klondike River two miles above its mouth, which he considered of minor importance. This is likely the same site examined in this study. The terrace occurs approximately 3 km upstream of the Klondike River on the Midnight Dome Road, at an elevation of 420 m (Figure 1). A minimum pre-Reid age is inferred for the gravel as the terrace occurs above the Reid surface (Figure 1b)

Recent mining of the site began in 1982 when W. Olson began downstream of Thomas Gulch with a small operation. W. Olson, Jr. presently operates a larger mine on the same site (Placer Mining Section, 1991; 1993). In 1988, testing of the terrace gravels by Lee Hall lead to production in 1989 and 1990 (Placer Mining Section, 1991). Gold was reported from the bottom 2-3 feet of gravel and ripped bedrock which contains nuggets, fine and coarse gold. T. Djukastein leased the property from Hall in 1992 and is continuing to mine the property with an operation which transports gravel to a sluice on dredge tailing piles in the valley bottom (Placer Mining Section, 1993).

Methods

As mining activity exposed new sections, detailed stratigraphic/sedimentologic logs were measured on a bed-by-bed basis. Sampling of individual beds included: measuring orientation of clasts to assess gravel fabric patterns, b-axis (intermediate) measurement of 10 largest clasts to determine maximum particle size (MPS), and sampling of representative beds from each facies for grain size analysis. Seven lithofacies are recorded, and summaries are presented generally following the system of Miall (1977).

Lithofacies description and interpretation

The intermediate terrace of this study represents a paleo-valley fill in which two fluvial environments dominated. The following description of lithofacies distinguishes pay gravels from overburden, and provides the basis for a geomorphic model which may be used to locate similar terrace placer deposits in central Yukon.

Facies 1: Massive to crudely imbricate sand matrix filled gravel (Gm)

The sediments of facies 1 are by volume the most significant of the terrace gravels seen in outcrop. They form the thickest, coarsest-grained unit, and occur

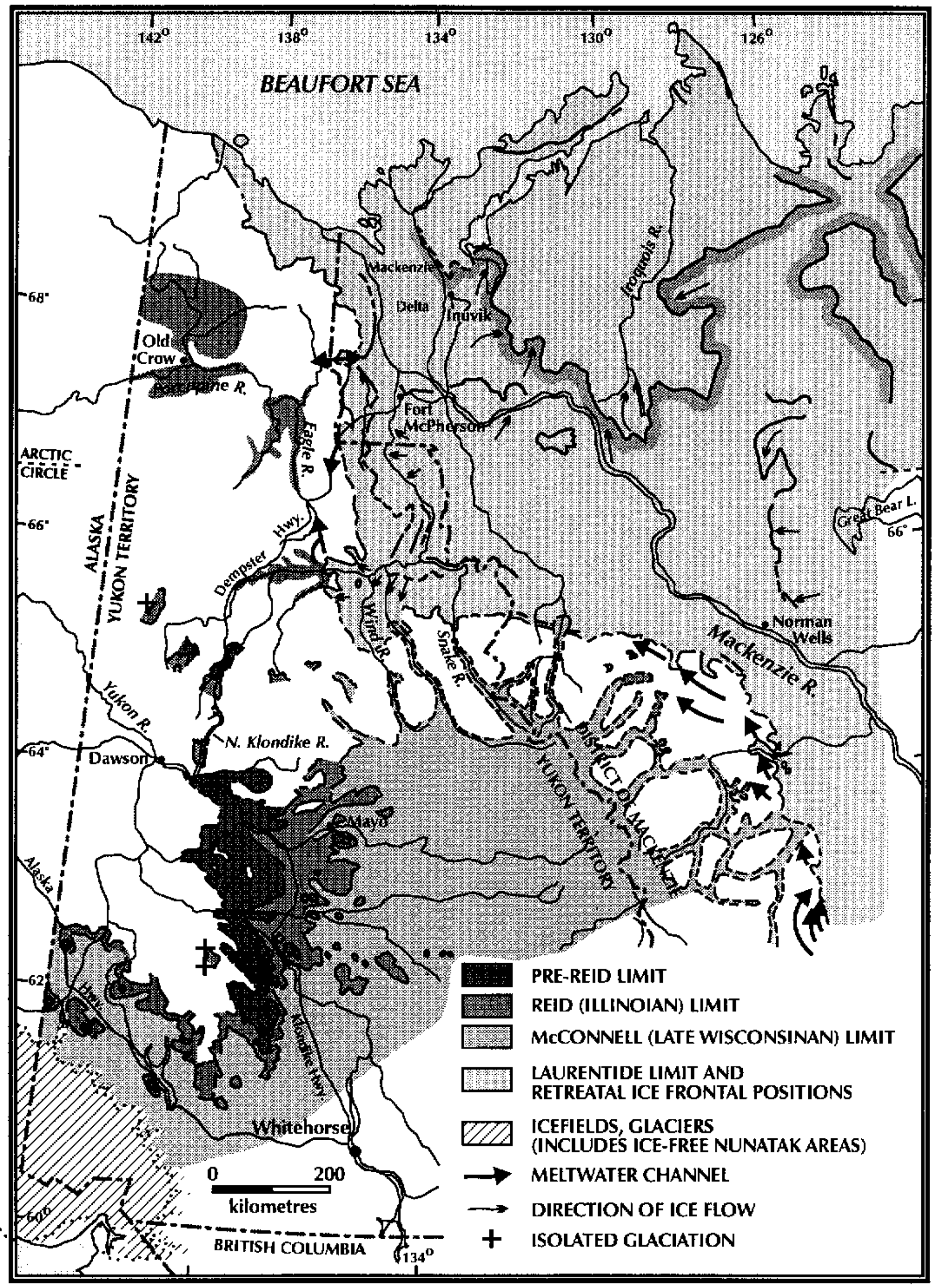


Figure 3: Maximum extent of glaciations in Yukon and western District of Mackenzie (from Hughes et al., 1969; Duk-Rodkin and Hughes, 1991).

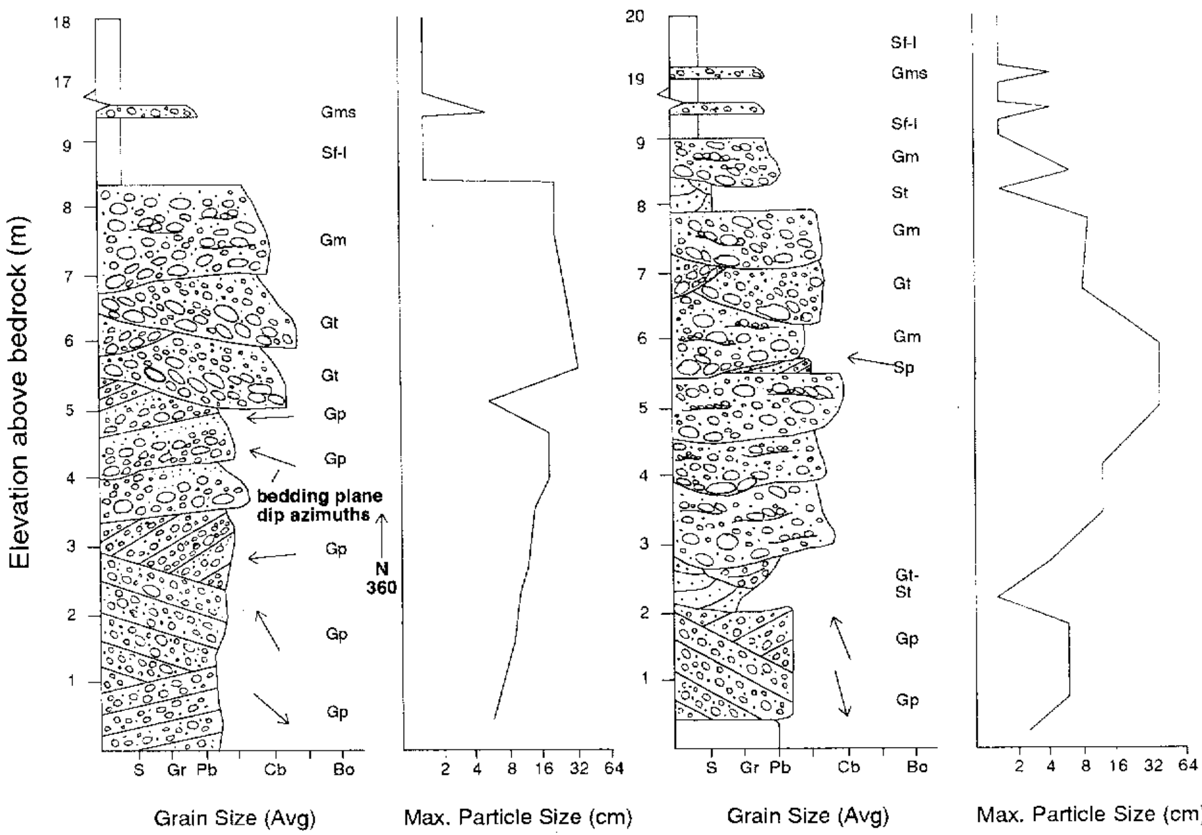


Figure 4: Sedimentologic logs of gravel facies from Djukastein and Olson mine sites (facies code after Miall, 1977). Note deviation in bedding plane azimuths in lowermost laterally accreted gravels (up to approximately 2.5 m) associated with greatest placer concentration (T. Djukastein, pers.com.). Abrupt change in maximum particle size (MPS: b-axis of the ten largest clasts) above 2.5 m corresponds to the change from an interglacial fluvial system to a proximal braided fluvial system. Gold concentrations of proximal braided gravels are uneconomic at the site.

from the middle to upper parts of mine exposure gravels. Facies 1 is a massive to crudely imbricate coarse cobble gravel with thin, well-sorted discontinuous intrabed lenses of coarse granules to fine pebbles (Figure 5C). These lenses are up to 10 cm thick and contain imbricated pebbles and cobbles in a matrix of coarse and medium sand. Clasts are sub-rounded to rounded with an average intermediate axis of approximately 15 cm, and a maximum particle size (MPS) of 34 cm. Imbrication is dominantly intermediate transverse to flow, though long axis imbrication is also observed. Weak cross-bedding, emphasized by variations in imbrication of large clasts, occurs in lateral exposures along mining pit walls. Facies 1 has a scoured base and thins downstream into planar tabular cross-bedded gravels (facies 3- Gp). Maximum observed facies thickness is 1.8 m.

Facies Gm resembles the 'diffuse gravel sheets' of Hein and Walker (1977), in which low relief forms are generated by the aggradation of gravel a few clast diameters above the bed. If a low ratio of water flow depth to clast size is maintained, aggradation of the gravel in its massive character occurs from the clast by clast accretion over an obstruction or lag deposit (Rust, 1978; Miall, 1977); but a flow depth to clast size ratio greater than 10 may form slip faces and cross-strata (Smith, 1985). Intrabed lenses within the facies are deposited during upper flow discharge when braid bars are submerged.

Facies 2: Cross-bedded gravel (Gt)

Facies 2 is a moderately to well-sorted gravel with cross-bedding and less common planar stratification and a sand matrix. Clasts are sub-rounded to rounded with an average intermediate axis of 6 cm, and a MPS of 15.8 cm. Matrix is estimated at 5-10%. Individual beds have scoured bases and are 30-50 cm thick with a maximum set thickness of 1.5 m. Cross-bedding is well defined when exposed parallel to flow. Facies Gt may reflect scour and fill of channels during high flow regime, or the secondary infilling of scour holes under lower flow. The generally shallow nature of the Gt cross beds (only up to 50 cm) suggests that scour and fill events occurred simultaneously.

Facies 3: Planar tabular cross-bedded gravel (Gp)

Facies 3 cross-bedding is readily apparent and may either infill channels up to 15 m wide or consist of unidirectional sets. Within the channel fills, high angle planar tabular cross-bedded sets occur at the base and show migration toward the steeper channel margins. This basal fill is capped by gravel with lower angle cross beds. The cross-bedded gravels locally exceed 1 m in thickness, with individual beds ranging from 4 to 20 cm (Figure 5B). Sorting is variable including open work well-sorted 2-3 cm gravel, and 6 cm gravel with a sand matrix. Clast imbrication is difficult to determine with smaller clast sizes, but imbrication parallel to dip is observed in high angle Gp, while lower angle stratification showed less clear imbrication. The dip azimuths between the planar tabular gravels have a wide divergence, up to 180 degrees (Figure 4).

Two origins are suggested for facies Gp. First, the cross-strata may result from the progradation of high relief bar forms into foresets. This explains the close relationship between facies Gm and Gp, (Hein and Walker, 1977; Smith, 1974) but it does not account for the strong deviation in observed dip azimuths of

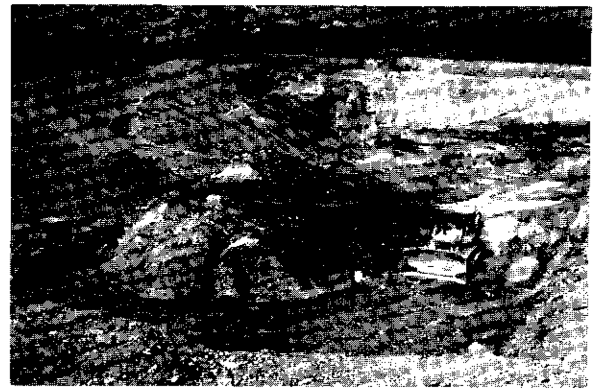


Figure 5A: North wall of Dujkastein pit with approximately 7 m of fluvial gravel overlain by approximately 11 m of unclassified fine grained sediment (see text for explanation).

Figure 5B: Facies 3 (Gp) low angle planar tabular cross-bedded gravel occurring above bedrock contact in association with highest gold placer concentrations, bedding plane dip azimuth 170° to left of photo; facies attributed to lateral accretion and channel shifting in a wandering gravel bed river, similar to the 'stable channels' of Desloges and Church (1987); approximately 3 m vertical section covered by photo.

the lower Gp facies of the Djukastein and Olson mine exposures (Figure 4). The second explanation is that cross-bedding may be a result of lateral accretion of barforms during bank full discharge.

Lateral accretion of channel gravels is indicated in the two west wall exposures of Figure 4 (A,B) which record Gp dip azimuths nearly perpendicular to the valley, and opposite dip directions over less than 1.5 m. In each exposure, the Gp facies form sets up to 15 m wide with a channel-like form, and have high angle sets near the base (near 15°) and lower angle inclination (8-10°) above. A similar mechanism of lateral accretion and channel shifting of gravel bed rivers has been ascribed to short duration peak flow and bank stabilization by McGowen and Garner (1970) and recognized in the stable channels of Desloges and Church (1987).

Facies 4 and 5: Cross-bedded sand and pebbly sand (Sp, St)

Trough cross-bedding within this facies may contain pebbles. Set thickness may reach up to 50 cm, but lateral extent is limited. Sand facies Sp show low angle inclination and planar form, less commonly with re-activation structures. The cross-bedded sands probably resulted from active foreset migration of bar fronts (Sp), or by shallow infilling of gravelly sand bedforms (St). Re-activation structures in facies Sp suggest fluctuating discharge levels with multiple periods of erosion and deposition.

Facies 6: Massive to finely laminated sand facies (Sf-l)

By volume, the sand of facies 6 is the most significant in the terrace successions, with a thickness up to 11 m. This massive unit of fine sand and silt overlies the terrace gravels. It contains minor graded laminations and matrix supported gravel diamict lenses (facies 7 below) greater than 40 m wide. Bedding characteristics, the presence of diamicts (facies 7) and the sharp transition from the underlying fluvial gravel suggest a lacustrine origin for the sands, which could indicate a major glacial lake in the Dawson area during the late-middle Pleistocene.

Given the loess record from unglaciated portions of Alaska (*e.g.* Westgate et al., 1990), and the near massive nature of much of the sediment, with minor laminations, an aeolian origin for the sediments of this facies cannot be ruled out. At the present time, the aeolian vs. sub-aqueous hypotheses are being considered. Continuing work will compare grain size characteristics with the Alaskan loess sediments and will examine the regional distribution of the facies, as well as identification of a volcanic ash and organic material found within the sediments.

Figure 5C: Facies 1 (Gm) massive to crudely imbricate coarse cobble gravel, part of 'proximal braided river assemblage' which is not associated with economic placer gold concentrations; field notebook 15 cm.

Facies 7: Massive to fining upward matrix supported gravel (Gms)

Within the sands and silts of facies 6, laterally extensive 30-40 cm lenses of matrix supported pebble gravel occur in excess of 40 m wide. These deposits consist of 30-40% silty clay matrix supporting rounded pebbles which were mainly derived from an overlying pre-Reid age terrace, and show in some cases crude upward fining. Facies Gms is the product of sediment gravity flows.

Discussion

Terraces are produced by incision of a floodplain which may result from changes in climate, baselevel and/or tectonics. In general, studies in glaciated environments relate terrace formation to a process of aggradation and incision resulting from changes in available sediment and discharge associated with fluctuating ice margins. This model for valley fill terraces would predict a relatively homogeneous package of gravel, which may show crude changes related to ice position, but would generally represent a single valley-fill event occurring in a relatively short period of time, perhaps hundreds of years. In the present study, the sedimentology of the intermediate terrace deposits indicates a more complex process with multiple environments of deposition over a greater time interval.

In the deposits of the incised valley-fill three facies assemblages are interpreted: 1. wandering gravel bed river assemblage; 2. proximal braided river assemblage; and 3. unclassified fine grained assemblage.

1. Wandering gravel bed river assemblage

A 'wandering gravel bed river', as defined by Church (1983) and Desloges and Church (1987), refers to a river with an irregularly sinuous channel, sometimes divided around channel islands, and in some reaches braided. Deposits of this type result from lateral accretion and channel migration in more stable reaches, similar to meandering streams; but in unstable reaches bars are more complex with more of a braided nature. Deposits attributed to wandering gravel bed rivers are still relatively rare in the geologic record, although this may be due to non-recognition of these deposits and their misclassification as braided gravels (Miall, 1982; Smith, 1989). In this study, the abrupt change in MPS in the vertical profiles at approximately 2 m, accompanied with the lateral accretion deposits (Figure 4), indicates the lowermost terrace gravel associated with the placer deposit was formed in a "wandering gravel bed" river. It should be noted that the lateral accretion deposits characteristic of this environment were only recognizable during and shortly after mining when exposures reached bedrock.

2. Proximal braided river assemblage

The crudely horizontally stratified gravels (Gm), which are abundant in the upper terrace gravels, may be interpreted as lag or braid bar deposits (Miall, 1977). The association of the crudely stratified gravels with other cross-bedded gravels containing scours and high angle, planar tabular cross-bedded structures (Gt, Gp), suggests a coarse-grained braided stream environment. In general, the cross-beds within lithofacies 2 are low angle and poorly defined above 2 m. Hein and Walker (1977) and Smith (1970) noted a trend toward better defined cross-stratification in more distal braided reaches, and a lack of high angle stratification in proximal reaches. Similarly, Boothroyd and Ashley (1975) found that the upper and middle reaches of the Scott outwash fan, proximal to the glacier, are characterized by massive, coarse braid bar gravels.

Implications for high level terrace placer exploration

The highest grade placer gold deposits represent a process of deposition in which significant time and stable sedimentary conditions have allowed continual reworking and concentration of heavy minerals (Schumm, 1977). Viewing a placer deposit in terms of facies assemblages provides a distinction between the relative placer potential of glacial vs. interglacial gravels. Proximal braided river gravels reflect rapid and continuous deposition of sediment, and as a result heavy minerals are expected to be distributed throughout the deposit, and potential for an economic concentration is low. Pay streaks are known to occur in braided gravels, but they tend to be erratic, or of relatively low value and volume (Levson and Morison, 1995). Studies of a wandering gravel bed river (the Bella Coola River in British Columbia) by Desloges and Church (1987) indicate that lateral migration of the channel in high sinuousity reaches reworks valley floor sediments at intervals of 145-165 years, providing an estimate of the potential to produce heavy mineral concentrations during an interglacial period.

In the present sedimentologic study of the intermediate terraces, at least four factors were important in producing and preserving the gold-bearing gravels. Firstly, a local gold source; secondly, a period of interglacial stability in which re-working of sediments concentrated heavy minerals. Thirdly, distal glacial input with mainly braidplain aggradation and little downgrading or incision of the underlying gravel. And finally, incision of the main Klondike valley following glaciation, with local preservation of the intermediate level.

The factors outlined above, necessary for the formation of the intermediate terrace placer gold deposit, have important implications for outlining other potentially economic terraces in central and northern Yukon. The pattern of successively less extensive glaciation from pre-Reid to McConnell has been well established (Bostock, 1966; Hughes et al., 1972; Duk-Rodkin and Hughes, 1991); and the limits of these events have been locally connected with high level terraces on the Stewart, Yukon and Klondike rivers (Fuller, 1994, 1995; Bond, this volume). This suggests that since these terrace surfaces may reflect valley floor aggradation conditioned by glaciation, interglacial gravels may be preserved beneath these outwash surfaces, with the gold values not reflected in the overlying outwash gravels. The geomorphic model is outlined in Figure 6.

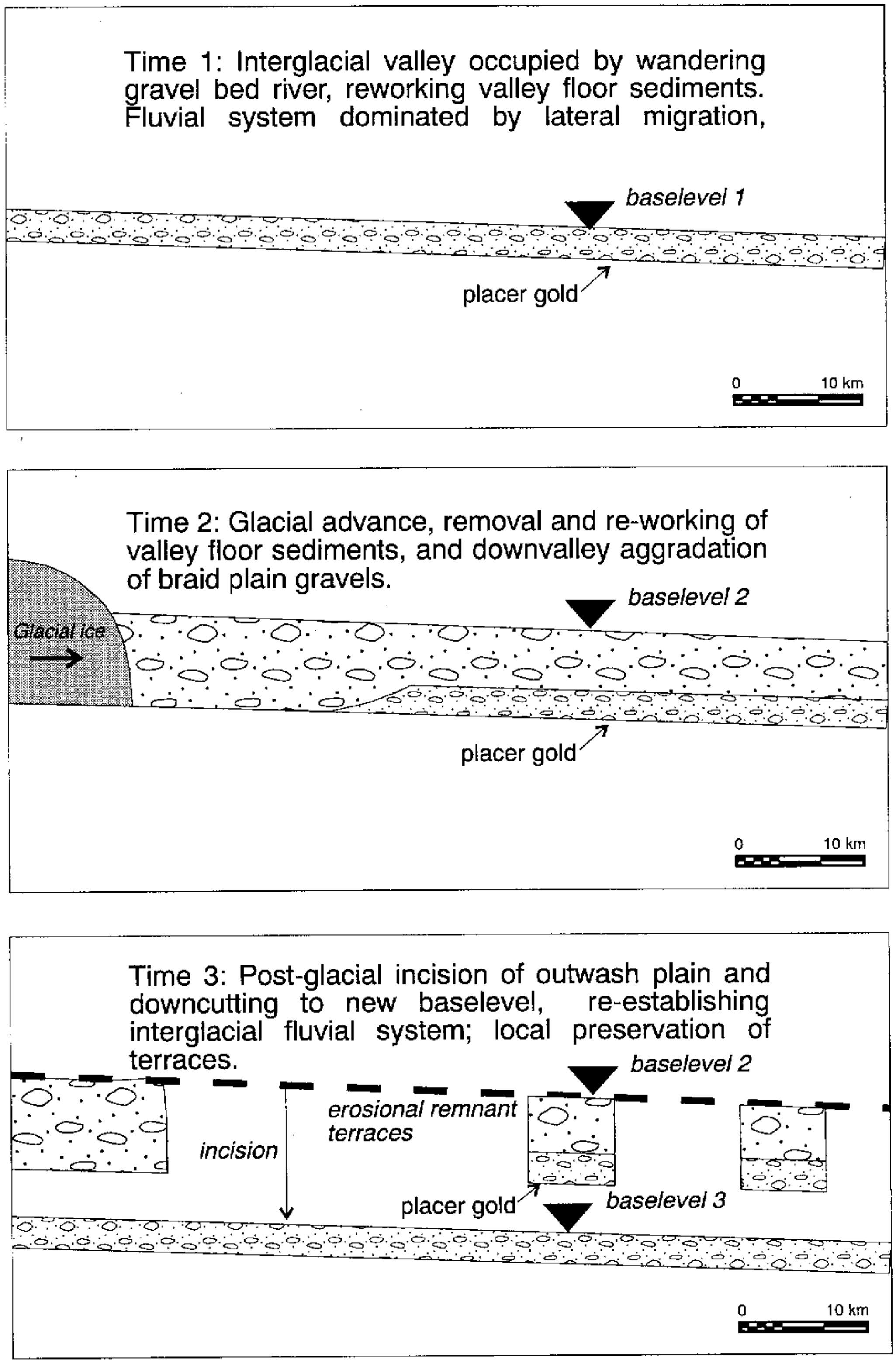


Figure 6: Geomorphic model for the development and preservation of a pre-Reid interglacial placer deposit at the Dome road terrace. This process of placer development may be applicable to other main valley high level terrace placer deposits in valley fills beyond the local end limit of glacial ice forming the terrace surface, in particular Stewart and Fortymile river terraces.

Conclusions

The geomorphic model in Figure 6 indicates that the presence of interglacial gravels may be critical to the formation of consistent high value terrace placer deposits in main valley settings; and these deposits may be buried in terraces by outwash gravels which do not reflect the gold values of the underlying gravel. This view of a placer, in terms of its broad depositional setting, distinguishes the often erratic pay streaks of glacial outwash from the more consistent values of interglacial gravels. It also suggests that modern stream gravels, formed under conditions similar to interglacial gravels, can be used as an indication of the placer potential of terrace gravels in the same valley, which occur downstream from the same gold source.

River terraces of the Stewart and Fortymile rivers seem to be good targets for exploration using this model. In each of these areas multiple glaciations have resulted in terrace formation, and each area has supported mining of modern river gravels. Further work on high level terraces in central Yukon should focus on outlining those terraces which have the greatest potential for preservation of interglacial gravels. This implies that the prospective targets are, first: valley fill rather than gravel veneer terraces; and second, those terraces beyond the local limit of glacial ice responsible for aggradation of the valley fill terrace surfaces where the interglacial gravel is less likely to have been reworked by the advancing glacier.

Acknowledgements

The work in this study is part of a regional surficial geology mapping program of the Dawson area, funded by the Yukon MDA Geoscience office and the Geological Survey of Canada. Thanks are due to A. Duk-Rodkin (GSC), for providing supervision and valuable comments. Derald Smith, University of Calgary, provided additional input and suggestions which improved this report. Bill LeBarge, Exploration and Geological Services, Northern Affairs Program, provided useful discussions in the field. Scott Barnes provided assistance in the field. A debt of gratitude is owed to T. Djukastein and staff, and W. Olson, Jr. for generous access to their mine sites and valuable information about placer deposits in the area.

References

BOOTHROYD, J.C., and ASHLEY, G.M. 1975. Processes, bar morphology and sedimentary structures on braided outwash fans, northeastern Gulf of Alaska. *In*: Jopling, A.V., and McDonald, B.C. (eds), Glaciofluvial and Glaciolacustrine Sedimentation: Society of Economic Paleontologist and Mineralogists Special Publication, 23, p.193-222.

BOSTOCK, H.S. 1966. Notes on glaciation in central Yukon Territory. Geological Survey of Canada, Paper 65-56, 18p.

CHURCH, M. 1983. Pattern of instability in a wandering gravel bed channel. *In*: J.D. Collinson and J. Lewis (Eds), Modern and Ancient Fluvial Systems. International Association of Sedimentologists, Special Publication, 6, p.169-180.

DESLOGES, R.J., and CHURCH, M. 1987. Channel and floodplain facies in a wandering gravel bed river. *In*: Recent Developments in Fluvial Sedimentology. Society of Economic Paleontologists and Mineralogists, Special Publication, 39, p.99-110.

DUK-RODKIN, A., and HUGHES, O.L. 1991. Age relationships of Laurentide and montane glaciations, Mackenzie Mountains, Northwest Territories. Geographie physique et Quaternaire, v. 45, no. 1, p.79-90.

DUK-RODKIN, A., BOND, J., JACKSON, L.E. Jr., and BARENDREGHT, R.W. 1995. Mid to Late Cenozoic record of glaciations in the northern Canadian Cordillera. Poster with Abstract presented at the Cordilleran Roundup, Vancouver, British Columbia, February 1995.

DYKE, A.S., and PREST V.K. 1987. Late Wisconsinan and Holocene retreat of the Laurentide Ice Sheet. Geological Survey of Canada, Map 1702A, scale 1:5 000 000.

FULLER, E.A. 1994. High level terraces along lower Stewart River and parts of Yukon River. *In*: Yukon Exploration and Geology, 1993, Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 15-28.

FULLER, E.A. 1995. High level terraces along parts of Yukon River and Sixtymile River. *In*: Yukon Exploration and Geology, 1994, Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 31-46.

GREEN, L.H. 1972. Geology of Nash Creek, Larsen Creek, and Dawson map-areas. Geological Survey of Canada, Memoir 364.

HEIN, F.J., and WALKER, R.G. 1977. Bar evolution and development of stratification in the gravelly braided Kicking Horse River, B.C. Canadian Journal of Earth Sciences, 14, p. 562-570.

HUGHES, O.L., CAMPBELL, R.B., MULLER, J.E., and WHEELER, J.O. 1969. Glacial limits and flow patterns, central Yukon territory south of 65 degrees north latitude. Geological Survey of Canada, Paper 68-34, 9p.

HUGHES, O.L., RAMPTON, V.N., and RUTTER, N.W. 1972. Quaternary geology and geomorphology, southern and central Yukon. XXIV International Geological Congress, Excursion A11, Guidebook, 59p.

HUGHES, O.L., RUTTER, N.W., and CLAGUE, J.J. 1989. Yukon Territory (Quaternary stratigraphy and history, Cordilleran Ice Sheet). *In*: Chapter 1 of Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.); Geological Survey of Canada, Geology of Canada, no. 1 (*also* Geological Society of America, The Geology of North America, v. K-1).

JACKSON, L.E. Jr., BARENDREGT, R.W., IRVING, E., and WARD, B. 1990. Magnetostratigraphy of early to middle Pleistocene basalts and sediments, Fort Selkirk area, Yukon Territory. *In*: Current Research, Part E, Geological Survey of Canada, Paper 90-1E, p. 277-286.

LEVSON, V.M., and MORISON, S.R. 1995. Geology of placer deposits in glaciated environments. *In*: Glacial Environments- Processes, sediments and landforms, J. Menzies (ed.), Permagon Press, Oxford, U.K.

McCONNELL, R.G. 1905. Report on the Klondike gold fields. Geological Survey of Canada, Annual Report 14, p. B1-B17.

McCONNELL, R.G. 1907. Report on gold values in the Klondike high level gravels. Geological Survey of Canada Publication 979, 34p.

McGOWEN, J.H., and GARNER, L.E. 1970. Physiographic features and stratification types of coarse-grained point bars: modern and ancient examples. Sedimentology, 14, p. 77-111.

MIALL, A.D. 1977. A review of the braided river depositional environment. Earth Science Reviews, 13, p. 1-62.

MIALL, A.D. 1982. Analysis of fluvial depositional systems. American Association of Petroleum Geologists course note series 20, 75p.

MILNER, M.W. 1977. Geomorphology of the Klondike placer goldfields, Yukon Territory. Indian and Northern Affairs Canada, Whitehorse, Yukon, Final Report.

MORISON, S.R. 1985. Sedimentology of White Channel placer deposits, Klondike area, west-central Yukon. Unpublished M.Sc. thesis, University of Alberta.

MORISON, S.R., and HEIN, F.J. 1987. Sedimentology of the White Channel Gravels, Klondike area, Yukon Territory: fluvial deposits of a confined valley. *In*: Recent Developments in Fluvial Sedimentology. Society of Economic Paleontologists and Mineralogists, Special Publication, 39, p. 205-215.

MORTENSEN, J.K. 1990. Geology and U-Pb geochronology of the Klondike District, west-central Yukon Territory. Canadian Journal of Earth Sciences, 27, p. 903-914.

NAESER, N.D., WESTGATE, J.A., HUGHES, O.L., and PEWE, T.L. 1982. Fission track ages of late Cenozoic distal tephra beds in the Yukon and Alaska. Canadian Journal of Earth Sciences, 19, p. 2167-2178.

PLACER MINING SECTION, 1991. Yukon Placer Mining Industry 1989-1990. Mineral Development Division, Yukon, Indian and Northern Affairs Canada, 125 p.

PLACER MINING SECTION, 1993. Yukon Placer Mining Industry 1991-1992. Mineral Development Division, Yukon, Indian and Northern Affairs Canada, 145 p.

RUST, B.R. 1978. Depositional models for braided alluvium. *In*: Miall, A.D.(ed.), Fluvial Sedimentology. Canadian Society of Petroleum Geologists, Memoir 5, p.605-625.

SCHUMM, S.A. 1977. The Fluvial System. John Wiley and sons, New York. 338 p.

SMITH, C.A.S., TARNOCAI, C., and HUGHES, O.L. 1986. Pedological investigations of Pleistocene glacial drift surfaces in the central Yukon. Geographie physique et Quaternaire, XL, no.1, p.29-37.

SMITH, N.D. 1970. The braided stream depositional environment: comparison of the Platte River with some Silurian clastic rocks, north-central Appalachians. Geological Society of America Bulletin, 97, p.2993-3014.

SMITH, N.D. 1974. Sedimentology and bar formation in the upper Kicking Horse River, a braided outwash stream. Journal of Geology, 82, p.205-223.

SMITH, N.D. 1985. Proglacial fluvial environment. *In*: Ashley, G.M., Shaw, J., and Smith, N.D. (eds.), Glacial Sedimentary environments: Society of Economic Paleontologist and Mineralogists Short Course Notes 16, p.85-134.

SMITH, S.A. 1989. Sedimentation in a meandering gravel-bed river: the River Tywi, South Wales. Geological Journal, v.24, p.193-204.

TEMPELMAN-KLUIT, D.J. 1976. The Yukon Crystalline Terrane: enigma in the Canadian cordillera. Geological Society of America Bulletin, 87, p.1343-1357.

TEMPELMAN-KLUIT, D.J. 1980. Evolution of physiography and drainage in southern Yukon. Canadian Journal of Earth Sciences, 17, p.1189-1203.

VERNON, P., and HUGHES, O.L. 1966. Surficial geology, Dawson, Larsen Creek, and Nash Creek map areas, Yukon Territory. Geological Survey of Canada, Bulletin 136, 25p.

WESTGATE, J.A., SEMPER, B.A., and PEWE, T.L. 1990. A 3 m.y. record of Pliocene-Pleistocene loess in interior Alaska. Geology, v.18, p.858-861.

QUATERNARY HISTORY OF MCQUESTEN MAP AREA, CENTRAL YUKON

Jeffrey D. Bond[1]

Bond, J.D. 1996. Quaternary History of McQuesten map area, Central Yukon. *In*: LeBarge W.P. (ed.), 1996. Yukon Quaternary Geology Volume 1, Exploration and Geological Services Division, Northern Affairs Program, Yukon Region, p. 27-46.

ABSTRACT

Preliminary results from the Stewart River stratigraphy and surficial mapping suggest a minimum of four glaciations and two interglacial periods. Methods of stratigraphy, paleomagnetics, soil analysis, tephra chronology, and relative geomorphic preservation are employed to differentiate and describe Quaternary events . Glaciations, from oldest to youngest, are the pre-Reid (multiple early to mid Pleistocene glaciations), Reid (> 200 000 years), and McConnell (14 000 - 29 600 years). Interglacials are represented by organic deposits from Stirling Bend and Ash Bend, in addition to the Wounded Moose and Diversion Creek paleosols preserved on pre-Reid and Reid surfaces.

During their maximum extent, pre-Reid ice sheets inundated the study area leaving isolated nunataks on Klondike Plateau and the northern part of Stewart Plateau near Syenite Range. North trending intervalley channels on Stewart Plateau represent confined ice flow in Stewart and McQuesten River valleys from ice obstructions in Tintina Trench. Undifferentiated pre-Reid surficial materials are thick in the lowlands of Klondike Plateau and Tintina Trench, areas proximal to the terminus of multiple pre-Reid glaciations. Reid ice terminated at Reid Lakes in the Tintina Trench. The McConnell ice sheet impinged into the east boundary of the study area, terminating approximately 20 km northeast of Stewart Crossing.

Petrographic analysis of woody material from the oldest pre-Reid deposit at Stirling Bend (unit A), suggest a late Tertiary age. Paleomagnetic measurements from overlying loess (unit B) and glaciofluvial sediments (unit C) have undetermined polarity. Remaining pre-Reid glacial and interglacial units from Stirling Bend have normal polarities and represent deposits from either a subchron within the Matuyama reversed chron or early Bruhnes normal chron. Reid deposits underlie Sheep Creek tephra at Ash Bend suggesting a minimum age of 200 000 years. McConnell deposits are Late Wisconsin age.

The distribution of surficial materials, related to multiple glaciations, physiography, and fluvial order contrasts, may govern the distribution of placer occurrences in McQuesten map area. Placer deposits occur anomalously in areas around Klondike Plateau, coinciding with the terminus of pre-Reid glaciations. Further exploration in pre-Reid ice terminal environments may yield significant placers through a better understanding of sediment distribution and genesis.

[1] Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta T6G 2E3.

Introduction

McQuesten Map area, central Yukon, contains a record of multiple glacial and interglacial events in the northern Cordillera. The stratigraphic record accounts for a minimum of four glaciations (pre-Reid (>200 Ka - multiple glacial episodes), Reid (>200 Ka), and McConnell (14 - 30 Ka)) and two interglacial periods represented by organic deposits and paleosols. This record is important to Quaternary research because it has an extensive record of glacigenic deposits that includes type localities with records of multiple glaciations, based on tills, glaciofluvial gravels, soils, and a tephra. In addition, rich interglacial deposits and paleosol studies form a basis for paleoclimatic reconstruction.

Surficial geology mapping in the McQuesten map area was initiated by O.L. Hughes of the Geological Survey of Canada (G.S.C.) in 1983 and later by A. Duk-Rodkin, also of the G.S.C., concentrating within the Reid glacial limits. The author resumed mapping and field studies in 1994 as part of a Master's project in association with the University of Alberta and the Geological Survey of Canada. This paper is an overview of preliminary results.

Study Area

The location of the McQuesten map sheet (NTS 115 P) is shown in Figure 1. The area forms part of the Yukon Plateau, a rolling upland surface ranging between 1000 m and 2000 m in elevation which is dissected by the Tintina Trench and Stewart River (Bostock, 1948; 1970) (Figures 1 and 2). Ogilvie and Wernecke Mountains lie on the north and the Klondike Plateau (Yukon Plateau) and Selwyn Mountains to the south and east, respectively. McQuesten map area is characterized by a subarctic continental climate, located within the widespread permafrost zone (Wahl et al., 1987). Permafrost is noticeable in the form of patterned ground, felsenmeer, and solifluction on upland surfaces and thermokarst ponds, pingos, and ground ice in valley bottoms (Brown, 1978; Burn and Friele, 1989; Burn, 1990, 1994).

Vegetation in the region is dominantly a northern mixed deciduous and coniferous forest. A combination of aspen (*Populus tremuloides*), grasses and white spruce (*Picea glauca*) are common on south-facing slopes. Boreal species such as black spruce (*Picea mariana*), white spruce and paper birch (*Betula papyrifera*) dominate north-facing slopes. Alpine regions consist of willows, ericaceous shrubs, shrub birch and alpine firs (*Abies lasiocarpa*) near treeline. Black spruce is also common on poorly drained sites in valley bottoms. Lodgepole pine (*Picea contorta*), aspen, paper birch, and white spruce dominate well-drained areas in valley bottoms (Oswald and Senyk, 1977).

Regional Geology

The regional geology of McQuesten map area includes North American strata, Yukon-Tanana Terrane, and intrusions which post-date accretion. (Gabrielse et al., 1977; Templeman-Kluit, 1979). Tintina Fault, with 450 km of dextral offset, separates North American strata from Yukon-Tanana terrane.

North American strata consist of sedimentary, metasedimentary and volcanic rocks of the Hyland, Road River, and Earn Groups (Murphy and Heon, 1994). Yukon-Tanana terrane or Yukon cataclastic complex comprises of ortho and para-gneiss, schist, quartzite and phyllite (Bostock, 1964; Hansen, 1990), accreted to North America in the late Jurassic. Post-accretion rocks include mid-Cretaceous and Tertiary felsic intrusions, primarily granite, monzonite, granodiorite, and syenite (Bostock, 1964; Ward, 1993).

Previous Research

McQuesten map area was first described by R.G. McConnell (1901) of the Geological Survey of Canada. His descriptions focused on bedrock and placer geology and led to research in the 1930s and 1940s by H.S. Bostock, also of the G.S.C. Bostock was first to note evidence of multiple glacial events in central Yukon and compiled the first map of glacial limits for central Yukon (Bostock, 1966). Bostock assigned the names Nansen (oldest), Klaza, Reid and McConnell (youngest) to the glacial limits he identified in central Yukon. Hughes et al. (1969) compiled the glacial limits and flow patterns, south of 65 degrees in Yukon. Geologic research continued through the 1960s and 1970s in surrounding map areas, in particular surficial geology investigations by Vernon and Hughes (1966) which were undertaken in the Ogilvie Mountains. McQuesten map area has been the focus of numerous pedological investigations which attempted to distinguish climate, soil processes, and relative age of drift surfaces related to multiple glaciations (Rutter et al., 1978; Tarnocai et al., 1985; Smith et al., 1986; and Tarnocai and Schweger, 1991). Recent Quaternary research has been carried out in the nearby Glenlyon (NTS 105 L) map area (Ward and Jackson, 1992; Ward, 1993), at Clear Creek (Morison, 1983), on Stewart River terraces (Fuller, 1994) and on Quaternary sedimentology and stratigraphy of McConnell and Reid age sediments near Mayo (Giles,

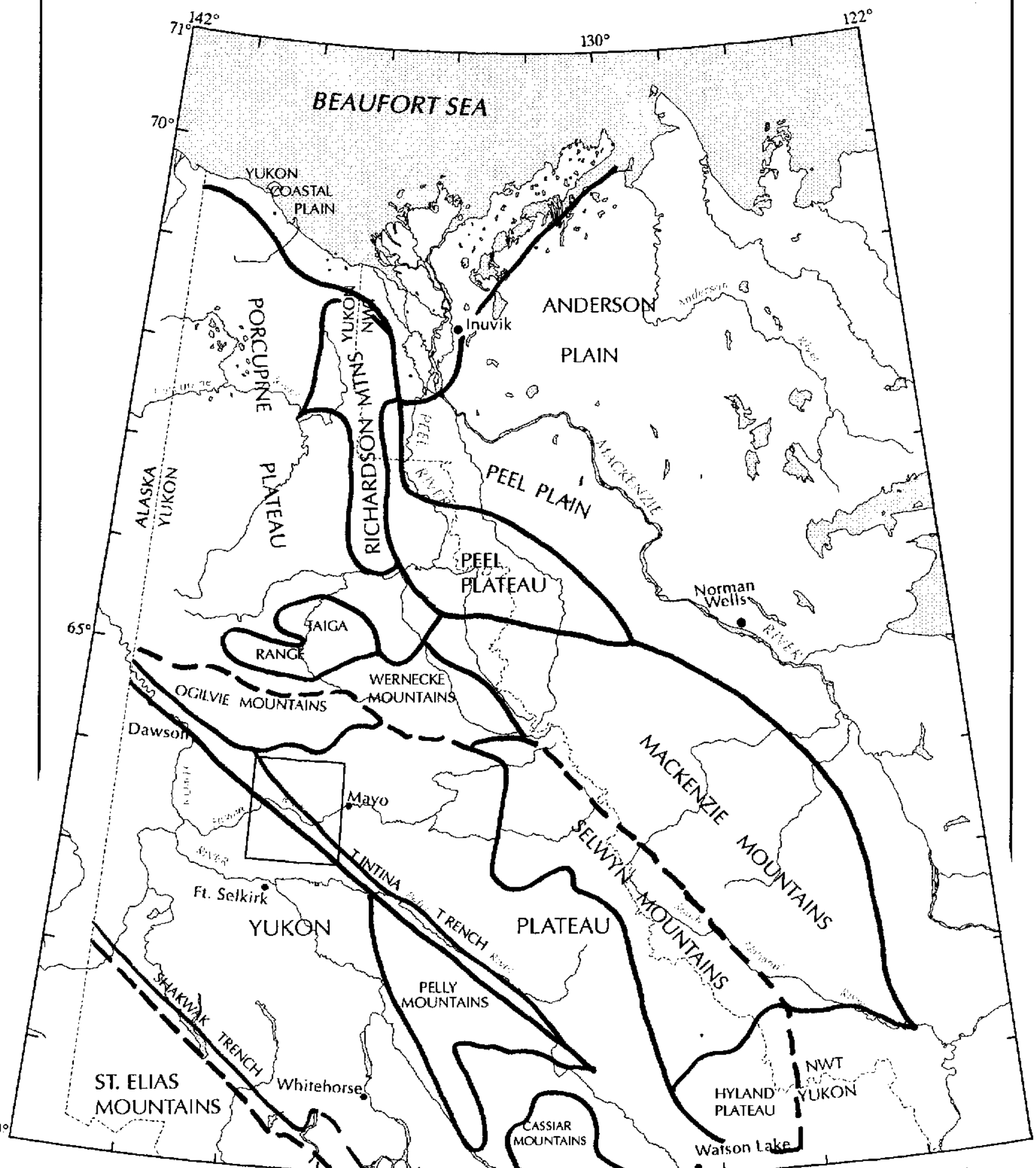


Figure 1: Physiography of Yukon Territory and location of McQuesten map area (after Bostock, 1970).

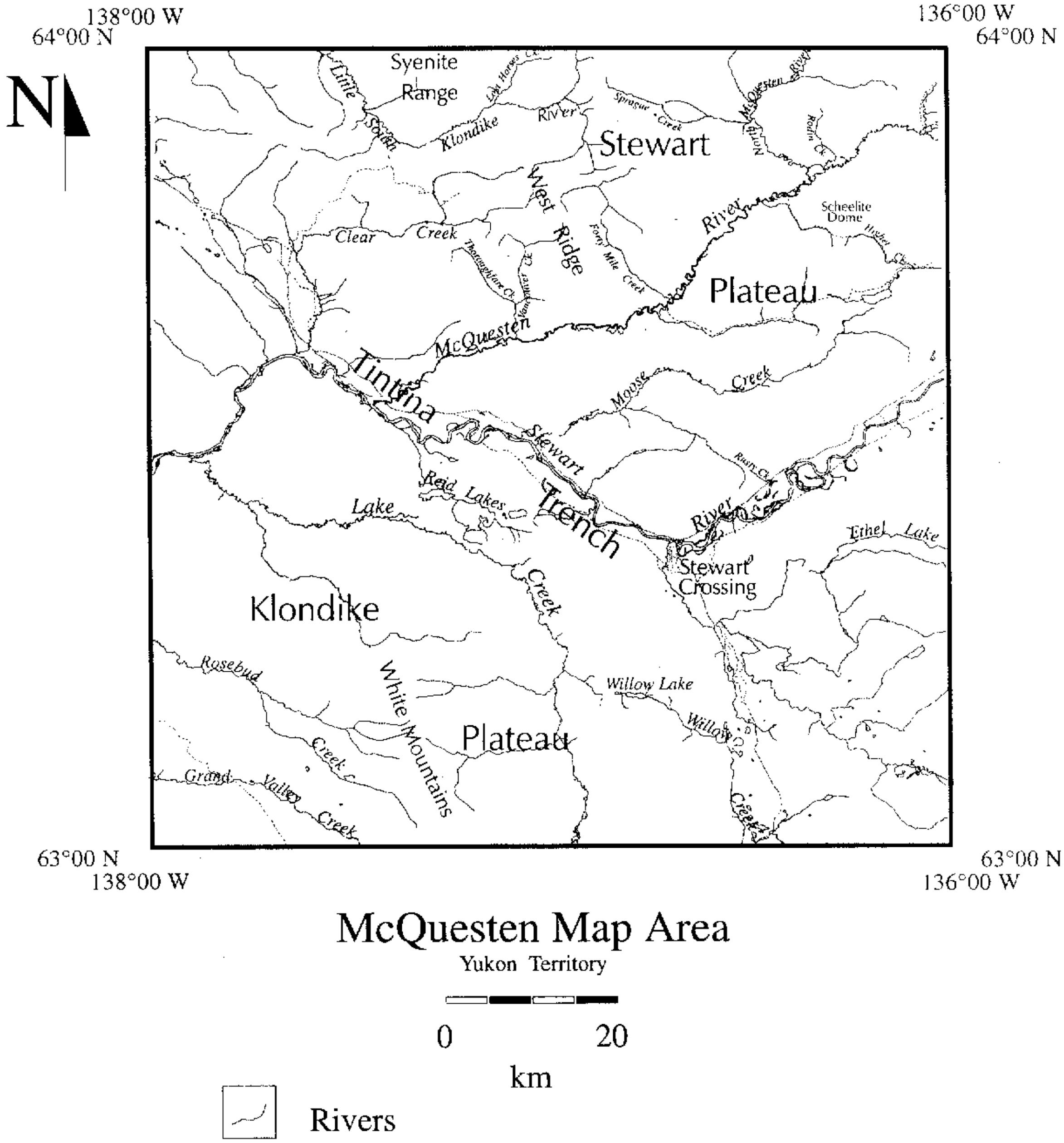


Figure 2: Location map, McQuesten area.

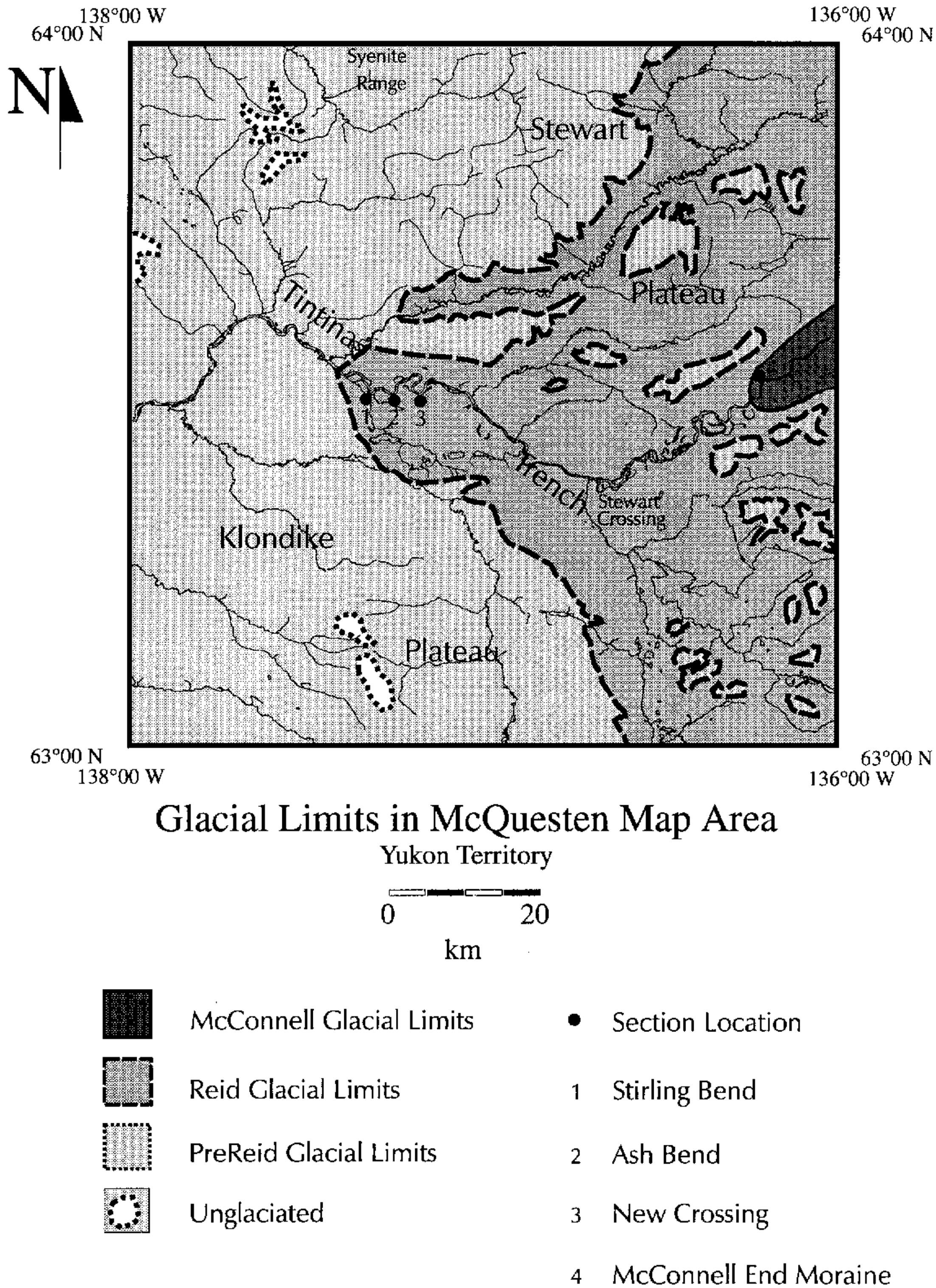


Figure 3: Glacial limits, McQuesten map area.

1993). L.E. Jackson of the G.S.C. is presently compiling the terrain inventory and Quaternary history of Carmacks map area (115I), which includes surficial geology maps 115I SE, SW, NE, and NW.

Late Tertiary - Quaternary Geology

Glaciations in central Yukon

Yukon Territory was affected by multiple glaciations during the Pleistocene. Ice accumulations in St. Elias Mountains, Pelly Mountains, Cassiar Mountains, and Selwyn Mountains combined to flow into the interior plateaus of central Yukon. Mapping of glacial limits has shown that successive Pleistocene glaciations were less extensive in central Yukon, accounting for the preservation of multiple glacial surfaces beyond the influence of later ice sheets (Figure 3). From oldest to youngest the main glacial episodes include the pre-Reid, Reid, and McConnell glaciations.

Pre-Reid glaciations include undifferentiated multiple early to middle Pleistocene advances, whereas the spatially well defined Reid and McConnell glaciations represent the last two glaciations in central Yukon. Soil formed during pre-Reid interglacial stages is preserved as the Wounded Moose paleosol (Tarnocai et al., 1985). The post Reid interglacial period developed the Diversion Creek paleosol, and the Holocene soil developed since the McConnell glaciation is referred to as the Stewart neosol (Rutter et al., 1978). Each soil has unique characteristics, which can be used to help identify drift age. Pre-Reid age glacigenic deposits cover about 60% of the McQuesten map area, whereas Reid and McConnell deposits cover about 38% and 2% of the map respectively. Of particular interest in McQuesten map area is the reuse of channels, carved during pre-Reid glaciation, by Reid and McConnell meltwater, showing a physiographic connection between glacial periods.

Pre-Glacial Drainage

The Yukon Plateau consists of an erosional surface that was elevated and incised during the late Tertiary. Remnants of the plateau occur as isolated uplands surrounded by broad valleys cut by fluvial and glacial processes (Templeman-Kluit, 1980).

Templeman-Kluit (1980) suggested that during the Miocene the paleodrainage of Yukon Plateau was southwesterly into the Pacific Ocean near the present day St. Elias mountains. Uplift of the Coast Mountains in the late Miocene, and the onset of glaciations that ensued, resulted in a regional reversal of drainage to the northwest (Templeman-Kluit 1980). In McQuesten map area, Templeman-Kluit (1980) identified misfit streams and underfit valleys to explain a preglacial regional tributary to the Yukon River. This river flowed southwest through Willow Creek valley, capturing water from Lake Creek valley, Tintina Trench, Stewart River valley, and Ethel Lake valley (Nogold Creek). In contrast, recent regional drainage reconstructions indicate the main channel of the south flowing paleo-Yukon River may have drained through part of the Tintina Trench and Willow Creek valley prior to glaciation (Duk-Rodkin, personal communication 1995).

This interpretation contrasts with original theories that suggest the Yukon River flowed within its original channel, anomalously across the north slope of the Dawson Range. Although pre-glacial fluvial deposits were not identified in the McQuesten map area, late Tertiary White Channel-like gravels lying on bedrock in the vicinity of Clear Creek are considered to be of pre-glacial origin (Bostock, 1966; Morison, 1983).

Regional Geomorphology of Pre-Reid Surfaces

Pre-Reid deposits are the oldest and most extensive glacial sediments in McQuesten map area. Pre-Reid ice extended across the Klondike Plateau, leaving thick glacial deposits in the Lake Creek drainage, Tintina Trench, and lowlands west of the White mountains. Pre-Reid ice sheets attained thicknesses well above later ice sheets: a minimum elevation of 1524 m at Scheelite Dome, on the eastern boundary of the map sheet, 1402 m on the White Mountains, west of Lake Creek, and 1280 m in the northwest corner of the map sheet. Unglaciated areas are marked by the development of cryoplanation terraces and/or tors (Figures 4 and 5).

Figure 4: Cryoplanation terraces on Flat Top Mountain in unglaciated terrain.

Figure 5: Tors on Willow Hills near the upper limits of pre-Reid glaciation.

Glacial flow on the Stewart Plateau was determined by the underlying topography, directing ice in a west-southwest direction. At the same time however, ice in Tintina Trench restricted flow in Stewart valley and McQuesten valley, which resulted in a series of north-trending transverse intervalley channels cut on the Stewart plateau (Figure 2). Both Thoroughfare Creek and the upper Little South Klondike River near Forty Mile Creek have abandoned channels that contained northward glacial flow on either flank of West Ridge (Figure 6). Pre-Reid glacial deposits on Stewart Plateau are confined to valley bottoms and less commonly to stable areas at higher elevations, such as meltwater channels, and elevated terraces in the vicinity of Clear Creek. Pre-Reid deposits may be present under thick accumulations of Reid and McConnell glacigenic sediments in the valleys of McQuesten River, Stewart River, lower Little South Klondike River, Ethel Lake valley, and Moose Creek valley.

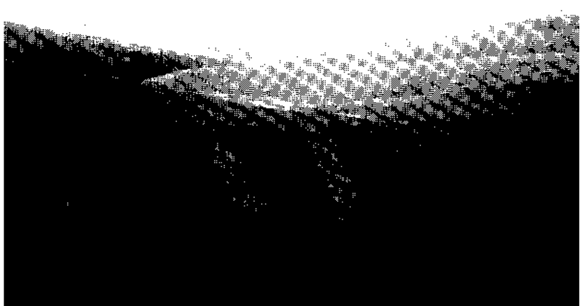


Figure 6: Northward view of a pre-Reid meltwater channel located between Little South Klondike River and Forty Mile Creek. The channel marks northward drainage across the Stewart Plateau during a pre-Reid glaciation.

Pre-Reid ice flow on the Klondike plateau was generally confined to northwest trending valley systems, with the exception of the north trending Lake Creek valley. Numerous valleys and meltwater channels breached upland areas like Willow Hills and White Mountains to contribute flow into Lake Creek and Rosebud Creek systems (Figure 7). Multiple levels of pre-Reid glaciation can be differentiated on the Klondike plateau, but landforms are too discontinuous to trace with certainty and retreatal landforms cannot be discerned from landforms of a separate glaciation. However, pre-Reid landforms are easily differentiated from the younger Reid and McConnell surfaces. Pre-Reid glacial deposits are particularly thick up to elevations of 762 m on Klondike Plateau, thinning to a veneer at about 1050 m.

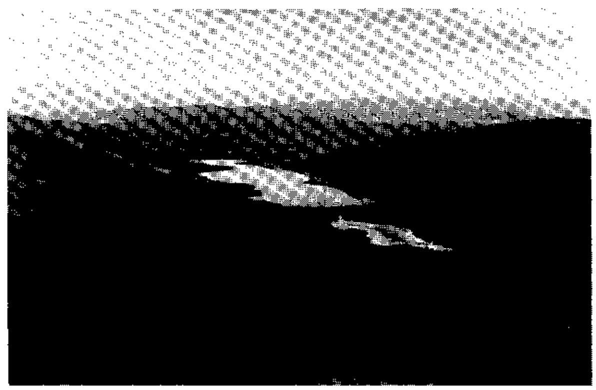


Figure 7: Eastward view of a pre-Reid channel dissecting the Willow Hills on Klondike Plateau, containing Willow Lake. The channel was also used by Reid meltwater.

Tintina Trench contains the thickest glacial deposits of pre-Reid age in McQuesten map area. Northwest of the mouth of Clear Creek, pre-Reid ice deposited at least one hundred meters of outwash and morainal sediments north to the Klondike valley near Flat Creek. This excessive fill and ice damming within Tintina Trench are likely responsible for diversion of Stewart River to the southwest across the Klondike plateau, assuming Stewart River did not drain to the west in pre-glacial time. Pre-Reid glacial sediments and the Wounded Moose paleosol (Tarnocai et al., 1985) can be identified in numerous road cuts along the Klondike Highway, north of Clear Creek.

Cirque glaciers developed in Syenite Range and radiated into Little South Klondike River, impinging into intervening highlands to the west. Ice in Klondike valley may have restricted flow from Little South Klondike River, forcing ice into these areas. Cirque glaciers also developed on West Ridge, contributing sediment into the Clear Creek drainage and upper Little South Klondike drainage. Additional ice and meltwater was supplied to the above drainages from South Klondike River valley through a divide on Lost Horses Creek, North McQuesten River valley ice through Sprague Creek, and McQuesten River valley ice through upper Thoroughfare and Vancouver Creek. Undifferentiated terraces were mapped in Little South Klondike valley, possibly related to pre-Reid outwash from these sources.

Pre-Reid Glaciations and Interglaciations

The pre-Reid events represent the earliest glaciations in central Yukon. The oldest Quaternary glacial sediments dated in central Yukon are early Pleistocene deposits from Fort Selkirk (Jackson, 1989; Jackson et al., 1990). The Fort Selkirk stratigraphic record, however, does not include glacial deposits of the older glaciation which was responsible for diverting the Yukon River to the northwest. Gravels below Jackson's oldest glacial deposit have a paleo-flow consistent with the present Yukon River, indicating an older glaciation must be unaccounted for (Jackson, personal communication 1995). In McQuesten map area at least two and possibly four pre-Reid glaciations have been identified on the Stewart River at Stirling Bend. Paleomagnetic measurement was employed to differentiate the McQuesten stratigraphy and surficial geology mapping was used to test earlier theories of multiple pre-Reid glaciations. Stirling Bend contains the most complete stratigraphy of pre-Reid glacial and interglacial sediments in McQuesten map area. Figure 8 shows the distribution of sediments and their recorded paleomagnetism. A total of 73 samples were collected from suitable fine grained beds for paleomagnetic work. Normal polarities were identified in all sampled units except for units B and C, which contained insufficient remnant magnetism.

Units A and B

Unit A, the oldest pre-Reid deposit, is a stratified diamict (mudflow) capped by a consolidated loess-like deposit (unit B) that overlies bedrock at the downstream end of the section (Figures 8 and 9). Although magnetization of unit B was too weak to determine a paleo-signal, the stratified diamict contains partially coalified non-coniferous woody material. Preliminary petrographic analysis of the sample indicated 0.14 percent of lignite, suggesting a late Tertiary age (Goodarzi, 1994). The intact nature of the sample suggests coalification likely occurred *in situ*. If the wood fragments represented reworked material then the depositional process, also involved in transporting boulder size clasts, would have shattered the coalified portion.

Figure 9: Units A and B at Stirling Bend consisting of a mudflow deposit (unit A), with boulder size clast, and loess-like sediments (unit B) capping the diamict.

Unit C and D

The oldest glacial deposits (units C and D) are the glaciofluvial gravels at either end of the section (Figure 8). Samples collected for paleomagnetism in unit C were too highly oxidized to obtain an accurate paleomagnetism. Sedimentary structures in unit C such as planar tabular cross bedding and coarse cobble supported gravel suggest a glaciofluvial origin (Figures 10 and 11). Samples collected from the upstream gravel (unit D) have a normal polarity with no overprints. Characteristics such as thick, massive cobble sequences with boulders and crude imbrication suggest a glaciofluvial origin (Figures 12 and 13). Based on the degree of oxidation and the strength of the remnant magnetism it is assumed unit C predates unit D.

Units E and F

White sands (unit E) stratigraphically overlie unit D, and are separated from unit C by a paleo-ice wedge cast (Figure 8). Stratigraphically unit E is younger than units C and D (Figure 8). Paleomagnetic signatures indicate a normal polarity for the white sands. Unit E has sedimentary structures such as climbing

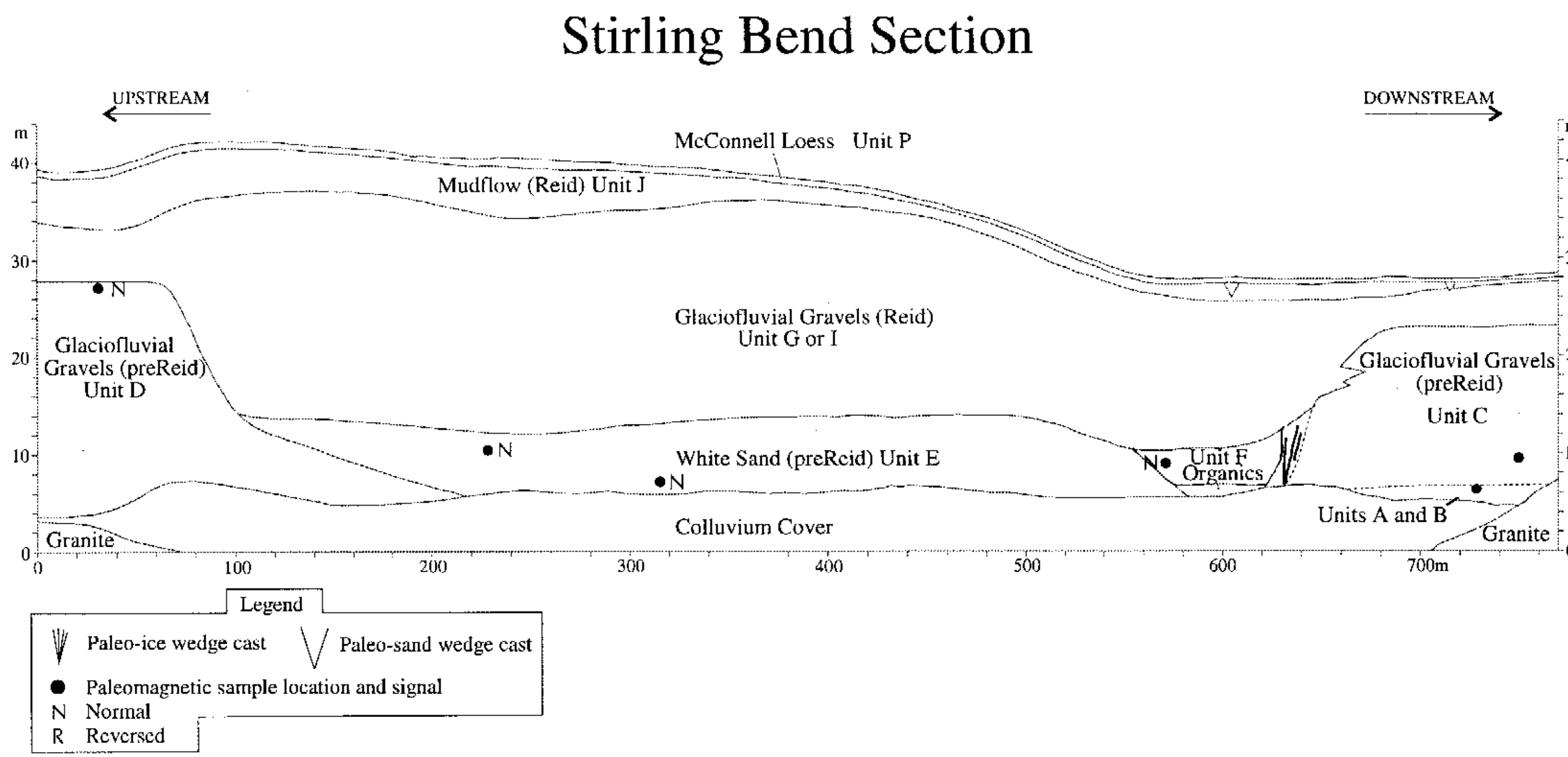


Figure 8: Stirling Bend Section with units and paleomagnetism.

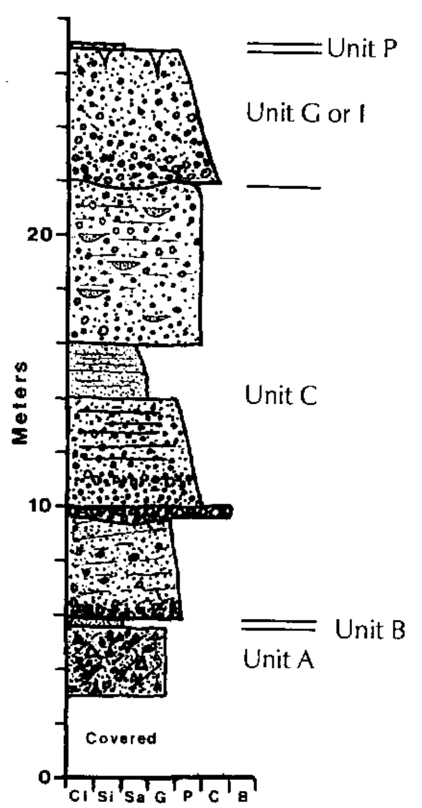


Figure 10: Stirling Bend stratigraphy and sedimentology at 740 m.

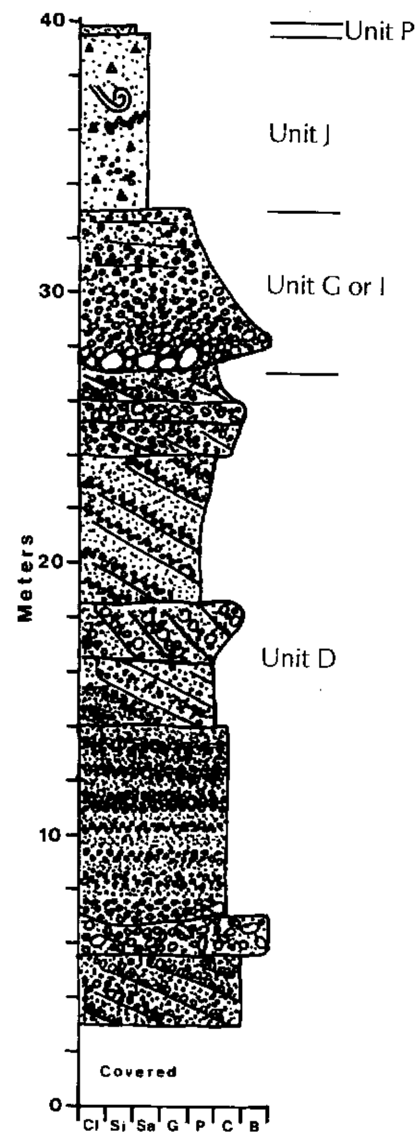


Figure 12: Stirling Bend stratigraphy and sedimentology at 40 m.

ripples, planar stratified laminar beds and lenses of diamict, suggesting a proglacial lacustrine environment (Figure 14). Glacial loading and dewatering of sediments have tilted and faulted the white sands, suggested by areas of high angle faulted bedding and involuted structures (Figure 14). Dissecting the white sands is an organic swale comprising a silty peat deposit capped by unsorted gravels (unit F) (Figures 8 and 15). Paleomagnetic samples from unit F have a normal polarity. The unit overlying the white sands and organics correlates with known Reid gravels at the Ash bend and New Crossing sections further upstream, and will be further discussed in the description of Reid sediments.

Units C, D and E represent depositional sequences related to glacial environments and provide evidence for at least two glaciations. Four pre-Reid glaciations are represented if unit A, the mudflow, and unit E, the white sands, are separate events. However, insufficient data are available to accurately determine the

Figure 11: Unit C, consisting of highly oxidized glaciofluvial gravels at Stirling Bend.

time of their deposition. The oldest glacial sediments are considered to be the downstream glaciofluvial gravels (unit C), based on degree of weathering and poorly preserved paleomagnetic signature relative to unit D. A tentative stratigraphic correlation between central Yukon and Mackenzie Mountains indicate unit D may be lower Bruhnes age (A. Duk-Rodkin, personal communication, 1995). The time period between the last pre-Reid glaciation from Fort Selkirk (approx. 0.780 Ma) and the Reid glaciations (>200 Ka) may incorporate as many as three cold periods according to the North Pacific deep sea record. Although these potential glacial periods have not been recognized in the geomorphic record of central Yukon, they may be represented in the Stirling Bend stratigraphy (units C, D, and E).

Tarnocai and Schweger (1991) identified a paleosol at Stirling Bend (Stirling Bend paleosol) below Unit F that has characteristics indicative of cryosolic soil development similar to that occurring in the Canadian Arctic at the present time. Pollen from the Stirling Bend paleosol and a preliminary pollen assemblage from unit F suggest a late-glacial to nonglacial period similar to that recorded for late Wisconsinan-Holocene sites elsewhere in the Yukon (Tarnocai and Schweger, 1991). A pre-Reid interglacial climate inferred from studies of the Wounded Moose paleosol suggests a former grassland environment in central Yukon that was sub-humid and warmer than today, later becoming more temperate and humid as indicated by the development of the Wounded Moose Luvisol with solum depths in excess of 190 cm (Rutter et al., 1978; Tarnocai et al., 1985; Smith et al., 1986; Tarnocai and Smith, 1989). A preliminary correlation between pre-Reid paleosols in McQuesten map area and a preliminary macrofossil and pollen assemblage from unit F at Stirling Bend suggest a climate as warm as or warmer than today.

Figure 13: Unit D, glaciofluvial gravels at Stirling Bend. Note at the bottom of the photograph the unsorted boulder facies indicative of a high energy depositional regime.

Regional Geomorphology of Reid Surfaces

Reid glacial sediments are confined to the major valleys within the Stewart plateau and Tintina Trench (Figure 3). At Scheelite Dome ice reached elevations of 1280 m and steadily declined from Tintina Trench to the terminus near Reid Lakes and the mouth of the

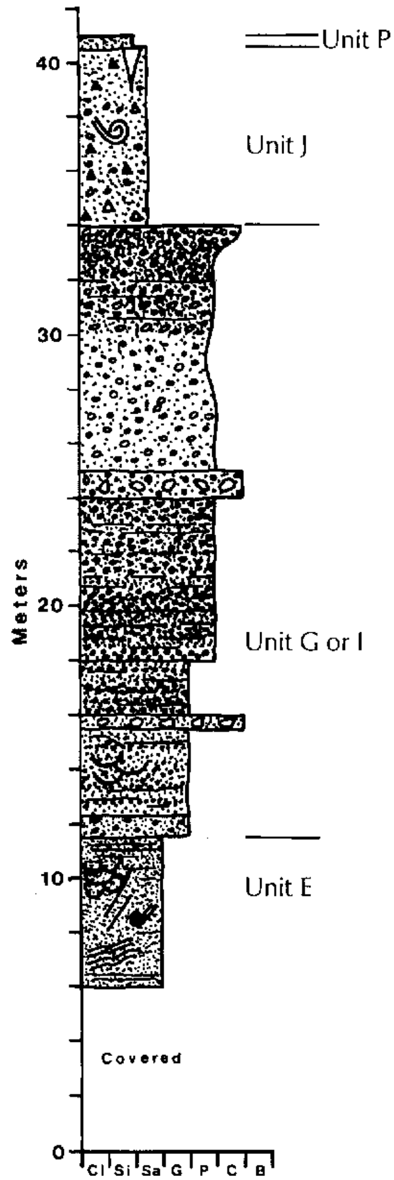


Figure 14: Stirling Bend stratigraphy and sedimentology at 240 m.

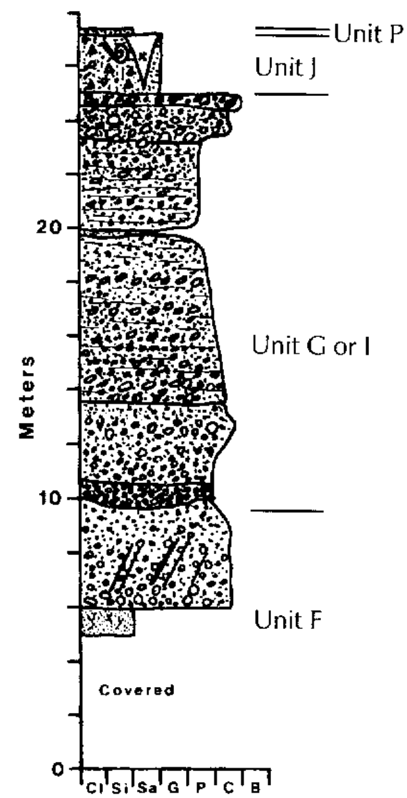


Figure 15: Stirling Bend stratigraphy and sedimentology at 640 m.

McQuesten River valley. A thick terminal moraine complex preserved at Reid Lakes forms the type locality for the Reid glaciation (Figure 2). Local cirque glaciers developed in Syenite Range and the eastern slope of West Ridge, possibly contributing to the development of glaciofluvial terraces in the Little South Klondike drainage. Well-defined glaciofluvial terraces are preserved in Tintina Trench and McQuesten River valley and can be traced downstream where they merge with McConnell age outwash terraces near the western edge of the map area.

Glacial damming of local drainages, transverse to regional flow, is evident in Rodin Creek and Highet Creek in the form of thick sand and silt sequences. At Highet Creek, preservation of the placer pay zone is attributed to development of a proglacial lake within the drainage prior to advance of Reid ice further up valley.

Reid Glaciation

Development of a colder climate following a long middle Pleistocene interglacial is indicated in the Wounded Moose paleosol by thermal contraction cracks induced by the Reid glacial climate (Figure 16) (Rutter et al., 1978). Three sections on Stewart River (New Crossing, Ash Bend, and Stirling Bend) document the environment during glacial maximum and form the main record of the Reid glaciation in the McQuesten map area (Figure 3).

Units G, H, I, J, K, and L

Ash Bend, in particular, contains a near complete Reid glacial stratigraphy including advance outwash (unit G), glacial diamict (unit H), retreatal outwash (unit I), and truncated Diversion Creek paleosol (unit L) (Figures 17 and 18). Reid age sediments at Stirling Bend (units G(or I)) may represent advance or retreatal outwash, but this is difficult to determine without reference to the Reid till (Figure 8, 12, 14, and 15). Unit J is a cohesive, convoluted, matrix- supported diamict with interspersed pebble lenses that caps Reid age outwash at Stirling Bend, Ash Bend and New Crossing sections. This unit is interpreted as a Reid deglacial mudflow (Figures 12, 14, and 15). Interglacial organics (unit K) containing organic silt, peat, Pleistocene vertebrate fossils, and Sheep Creek tephra from the last interglacial are incised into Unit I at Ash Bend (Hughes et al., 1987). Sheep Creek Tephra has been dated at 200 Ka, coinciding with oxygen isotope stage 7 (Berger, 1994). An age of ca. 200 Ka for Sheep Creek tephra suggests the Reid glaciation had to occur at or before isotope stage 7.

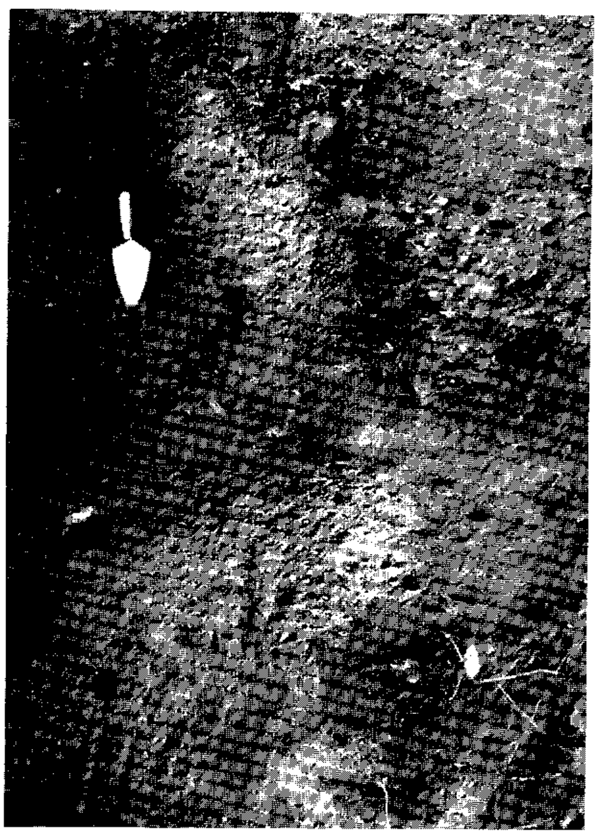


Figure 16: Reid age paleo-sand wedge cast in the Wounded Moose Paleosol near Clear Creek crossing.

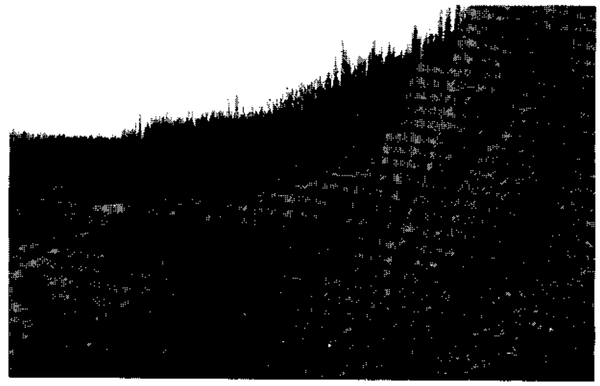


Figure 18: Ash Bend section on Stewart River near the terminus of the Reid glaciation. The cohesive till, unit H, separates advance and retreat outwash units G and I.

Post Reid Interglacial

Formation of the Diversion Creek paleosol occurred between the Reid and McConnell glaciations and is partially preserved at many sites as a truncated soil below McConnell age loess. The Diversion Creek paleosol is an Orthic Eutric Brunisol (paleo) indicative of a cool subhumid climate (Smith et al., 1986; Tarnocai and Smith, 1989). Deposition of the organic silt bed and Sheep Creek tephra at Ash Bend occurred at this time, providing a minimum age for the last interglacial period and probably the most complete paleoecological record in McQuesten map area. A detailed pollen assemblage has yet to be documented from this deposit.

Regional Geomorphology of McConnell Surfaces

The McConnell glaciation reached the eastern edge of McQuesten map area, terminating approximately 20 km upstream from Stewart Crossing (Figure 3). A distinct terminal moraine complex was deposited in Stewart River valley in addition to glaciofluvial outwash in Stewart River valley, McQuesten River valley and the Tintina Trench. Katabatic winds from McConnell full glacial conditions deflated and truncated the Diversion Creek paleosol that developed on Reid loess. Loess derived from McConnell outwash

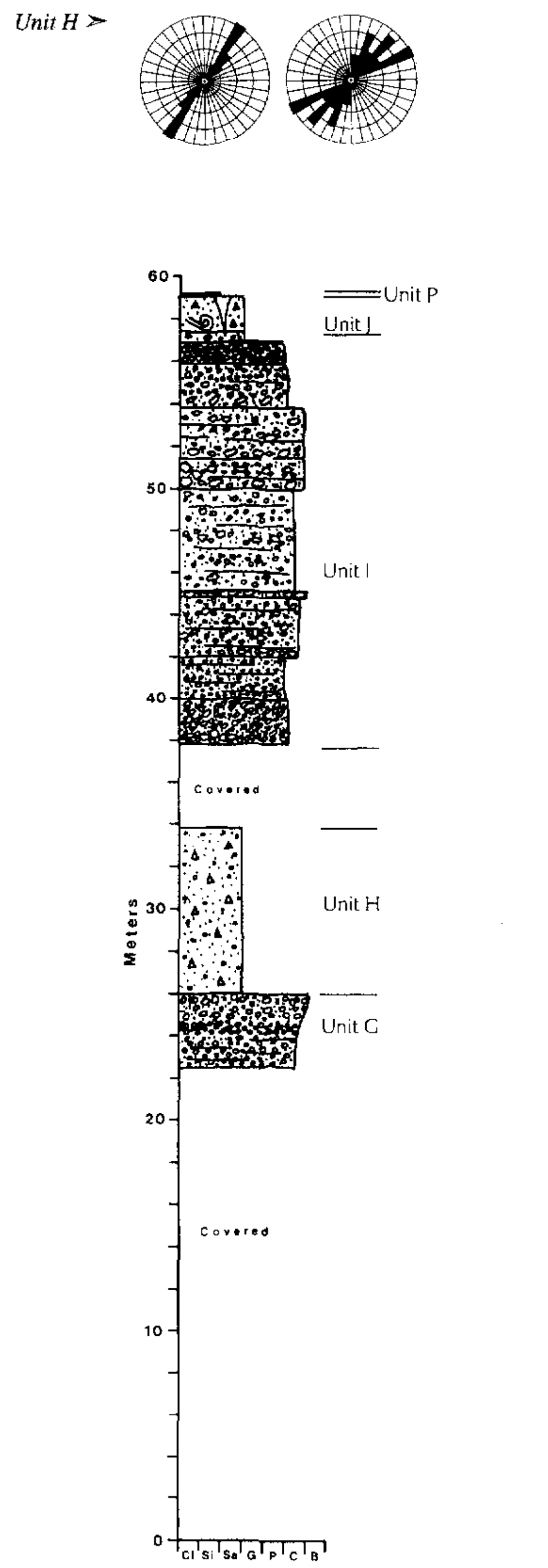


Figure 17: Ash Bend stratigraphy and sedimentology with till fabric diagrams.

plains was redeposited as a veneer over Reid and pre-Reid surfaces (unit P). Dunes developed on glaciofluvial outwash of McConnell age and in some instances Reid aeolian deposits were reactivated in the vicinity of upper Moose Creek and Rusty Creek, both areas beyond the influence of McConnell glaciogenic deposition.

McConnell Glaciation

The stratigraphy contained within the McConnell end moraine complex records glacial activity at the maximum of the last glaciation (Figure 3). The end moraine sections contain advance outwash (unit M), till (unit N), retreatal outwash (unit O), and loess (unit P) (Figures 19 and 20).

Figure 20: McConnell age advance outwash (unit M) capped by till (unit N) at the terminus of the last ice sheet in Stewart River valley.

The onset of the McConnell glaciation had begun by 29.6 Ka according to a C^{14} date and paleoenvironmental reconstruction from detrital organics below McConnell age till near Mayo (Matthews et al., 1990). Ice free conditions persisted near Ross River at 26.3 Ka, and the glacial maximum probably did not occur in McQuesten map area until sometime after 18 Ka (Jackson and Harington, 1991). This date suggests a Late Wisconsinan age for the McConnell glaciation. The developing McConnell glacial environment and full glacial conditions resulted in thermal contraction cracks and frost shattering of clasts on Reid and pre-Reid surfaces. Ice wedges that formed during McConnell glaciation were narrower than Reid ice wedge cracks, suggesting a short but intense glaciation (Rutter et al., 1978).

Ground Squirrel (*Spermophilus parryi*) bones collected from a sand wedge on Reid outwash at Stirling Bend provide an AMS date of 11.5 Ka (Figure 15). This age suggests periglacial conditions persisted in the McQuesten area well after retreat of the

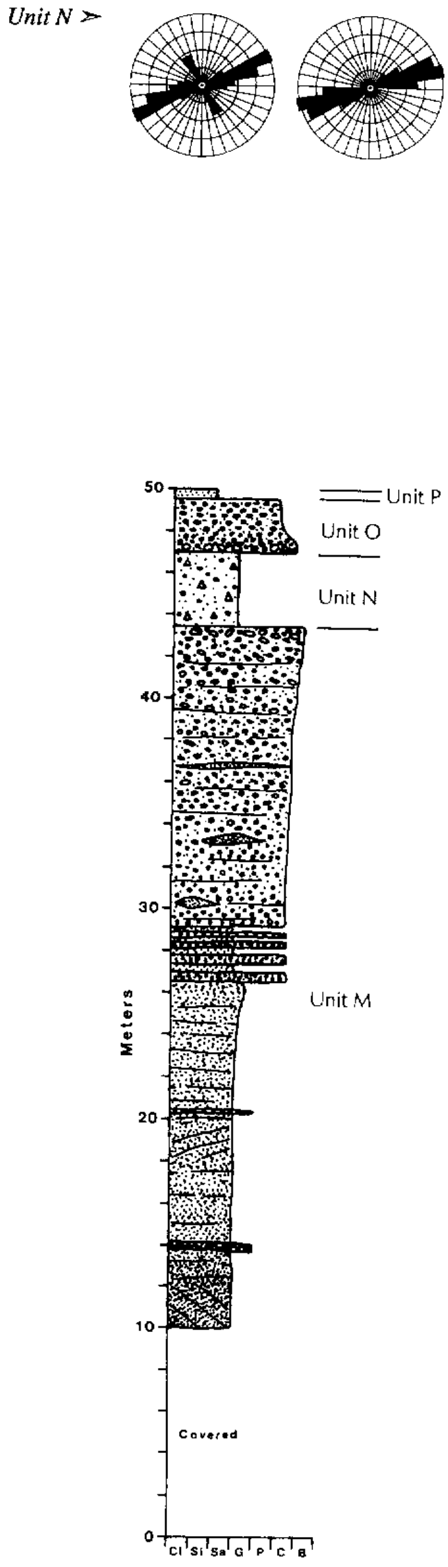


Figure 19: McConnell end moraine stratigraphy and sedimentology with till fabric diagrams.

Cordilleran ice sheet from the region. A date from Jake's Corner, south of Whitehorse, indicates that southern Yukon was ice free by 11.3 Ka (GSC-3831, McNeely, 1991).

Holocene

The development of the Stewart neosol on McConnell deposits is the result of a subarctic-subhumid post-glacial climate, followed by the subarctic-semiarid climate of today in central Yukon (Zoltai and Tarnocai, 1974). The Stewart neosol has characteristics indicative of an Orthic Eutric Brunisol (Rutter et al., 1978; Smith et al., 1986). Dissection of glacial sediments continued in Stewart valley, McQuesten valley, and Tintina Trench, exposing the current stratigraphy and building a modern alluvial plain.

Regional Geomorphology and Implications for Placer Research

The geomorphology of the McQuesten area reflects the nature of the physiography and the effects of several periods of glaciation. Displacement of the Yukon plateau by Tintina Fault has created two physiographic plateaus with contrasting topography and fluvial order. These factors are important in the location of current placers in McQuesten map area.

Stewart Plateau, northeast of Tintina Fault, generally has steeper slopes and consistently higher terrain whereas the Klondike plateau, southwest of Tintina Fault, is characterized by broad valleys, relatively gentle slopes, and a lower average elevation. These physiographic differences have also affected the thickness and distribution of the surficial materials in the map area. Stewart Plateau has higher relief which confined glacial deposition to valley bottoms and lower flanks of valley sides. Surficial sediments on Klondike plateau are more evenly distributed, meaning glacial deposits are more likely to be found at higher elevations. In addition, Klondike Plateau was closer to the terminus of pre-Reid glaciations than Stewart Plateau, where typically thicker accumulations of glacial sediments were deposited under the influence of glacial processes in the vicinity of terminal areas. This is exemplified in the Reid and McConnell terminal moraines. Extension of pre-Reid ice into McQuesten map sheet from the south was enhanced by the northwest trending Dawson Range which provided a barrier against the west and northwest flowing Cordilleran ice, and redirected ice flow into the lowlands of Lake Creek, Grand Valley, and Willow Creek. This concentration of flow contributed to excessive glacial sedimentation on Klondike Plateau in McQuesten map area.

Fluvial systems are different between the Stewart and Klondike Plateaus. Major drainages on the Stewart plateau have headwaters in the Selwyn Mountains, emitting larger rivers across the plateau. This combination of higher order river systems and more vertical relief accounts for greater erosion and redistribution of surficial sediments, especially those of pre-Reid age. In contrast, Klondike Plateau contains only local drainages, such as Lake Creek and Grand Valley Creek, which have proximal headwaters and consequently low order discharges and capacity for erosion.

Placer occurrences in McQuesten and surrounding map areas are generally confined to unglaciated environments, areas of sparse glacial sediments, or high relief drainages (gulch-like placer accumulations). These attributes have no doubt been governing factors in the location of past and current placer mines in central Yukon. It is probable, based on the presence of placers in surrounding regions, that Klondike Plateau in McQuesten map area has potentially significant placer occurrences. Exploration has likely been limited to glacial deposits that do not actually reflect the true quantity of naturally occurring placer gold. In this scenario nonvigorous local streams have yet to downcut through a placer deposit, hence, factors of topography, fluvial setting, and excessive glacial fill have hindered placer exploration. Streams on the Stewart plateau, on the other hand, have undergone base level adjustment following glaciation resulting in downcutting of streams through glacial sediments and auriferous interglacial gravels.

Finally, reconcentration of placer gold in a glaciofluvial setting should not be overlooked in McQuesten map area. Large volumes of outwash have scoured and redistributed interglacial pay units and could, potentially, act as an environment for placer accumulation. The main drawback is thick overburden that would hamper exploration efforts. Application of new technology in geophysics and drilling, in addition to extensive field sampling and understanding of preglacial environments and glacial processes, could overcome this problem.

Conclusions

The Quaternary record in McQuesten map area provides stratigraphic evidence of at least four glaciations. A section at Stirling Bend on the Stewart River contains pre-Reid sediments that include at least two glacial units and an interglacial deposit. Paleomagnetic sampling of pre-Reid deposits yielded normal magnetisms for all except the two oldest units, which had insufficient remnant magnetism to determine a polarity. The pre-Reid units were deposited either during a subchron within the Matuyama reversed chron or represent early Bruhnes glaciations. The Ash Bend section contains a complete record of Reid glacial sediments that incorporate pre-glacial outwash, till, post-glacial outwash, Diversion Creek paleosol, and last interglacial organics containing Sheep Creek Tephra. The Reid glaciation occurred at or prior to Oxygen Isotope stage 7, but the timing of the Reid glaciation is vague and warrants further investigation to complete the middle Pleistocene record for central Yukon. Late Wisconsinan McConnell age deposits are preserved on the Stewart River, east of Stewart Crossing, and consist of glacial maximum outwash and till. Periglacial conditions persisted in McQuesten map area until at least 11.5 Ka.

Surficial geology mapping and field investigations described the character of surficial sediments and their distribution. Glacial deposits are more widespread on Klondike Plateau because of physiography, low order drainages, and proximity to the terminus of the pre-Reid glaciations. In contrast, glacial deposits on Stewart Plateau are more confined to lower slopes and valley bottoms of regional drainage systems. Tintina Trench contains a thick Pleistocene record of glaciofluvial outwash terraces and drift plains.

The contrasting geomorphic setting in McQuesten map area may govern the distribution of placers. A better understanding of pre-Reid glaciations on Klondike Plateau and how this affects placer exploration could reveal new prospects in McQuesten map area.

Acknowledgements

Special thanks are due to A. Duk-Rodkin of the Geological Survey of Canada for establishing this project and for her continued support. The Geological Survey of Canada, Circumpolar Institute, and N.W. Rutter (NSERC) funded field investigations. Valuable comments were given by A. Duk-Rodkin who critically reviewed this paper. Additional review, and insights regarding the timing of McConnell ice in the McQuesten area, was provided by D. Froese. R. Barendregt generously conducted the paleomagnetic program and capable field assistance was provided by M.Geisbrecht. I am also grateful to T. Heah and R. Hulstein (Kennecott Canada, Inc.) who enthusiastically supported geomorphic evaluations in McQuesten map area during the summer of 1995.

References

BERGER, G.W. 1994. Age of the Alaska/Yukon Sheep Creek tephra from thermoluminescence dating of bracketing loess at Fairbanks. A bridge of the science between North America and the Russian Far East. Paper presented at the 45th Arctic science conference, 25-27 August, 1994, Anchorage, Alaska-29 August-2 September, 1994, Vladivostok, Russia.

BOSTOCK, H.S. 1948. Physiography of the Canadian Cordillera, with special reference to the area north of the fifty-fifth parallel. Geological Survey of Canada, Memoir 247, 106 p.

BOSTOCK, H.S. 1964. McQuesten. Geological Survey of Canada, Map 1143A. Department of Energy and Mines.

BOSTOCK, H.S. 1966. Notes on glaciation in central Yukon Territory. Geological Survey of Canada, Paper 65-36, 18 p.

BOSTOCK, H.S. 1970. Physiographic regions of Canada. Geological Survey of Canada, Map 1254A.

BROWN, R.J.E. 1978. Permafrost: Plate 32. *In*: Hydrological Atlas of Canada, Ottawa, Fisheries and Environment Canada.

BURN, C.R. 1990. Implications for Paleoenvironmental Reconstruction of Recent Ice-wedge Development at Mayo, Yukon Territory. Permafrost Periglacial Processes, 1: 3-14.

BURN, C.R. 1994. Permafrost, tectonics, and past and future regional climate change, Yukon and adjacent Northwest Territories. Canadian Journal of Earth Sciences, 31: 182-191.

BURN, C.R. and FRIELE, P.A. 1989. Geomorphology, vegetative succession, soil characteristics and permafrost in retrogressive thaw slumps near Mayo, Yukon Territory. Arctic, 42: 31-40.

FULLER, E.A. 1994. Surficial geological map of Stewart River valley, parts of 115O/8, 115P/5, and 115P/12, central Yukon. Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, Open File 1994-7(G), 1:50,000.

GARIELSE, H., TEMPLEMAN-KLUIT, D.J., BLUSSON, S.L. and CAMPBELL, R.B. 1977. Macmillan River, Yukon-District of MacKenzie-Alaska, Map 1398A. Geological Survey of Canada, Department of Energy Mines and Resources.

GILES, T.R. 1993. Quaternary Sedimentology and Stratigraphy of the Mayo Region, Yukon Territory. Unpublished Master of Science Thesis, Department of Geology, University of Alberta, Edmonton, Alberta.

GOODARZI, F. 1994. Petrographical analyses on wood sample (pellet number 1595/94). Unpublished document, Geological Survey of Canada.

HANSEN, V.L. 1990. Yukon-Tanana terrane: a partial acquittal. Geology, v. 18, p. 365-369.

HUGHES, O.L., CAMPBELL, R.B., MULLER, J.E. and WHEELER, J.O. 1969. Glacial limits and flow patterns, Yukon Territory, south of 65 degrees North latitude. Geological Survey of Canada, Paper 68-34, 9p.

HUGHES, O.L., HARINGTON, C.R., SCHWEGER, C., and MATTHEWS, J.V. Jr. 1987. Stop 15: Ash Bend Section. *In* : Guidebook to Quaternary Research in Yukon, S.R. Morison and C.A.S. Smith (eds.). XII INQUA Congress, Ottawa, Canada. National Research Council of Canada, Ottawa, pp.50-53.

JACKSON, L.E. Jr. 1989. Pleistocene subglacial volcanism near Fort Selkirk, Yukon Territory. *In*: Current Research, Part E, Geological Survey of Canada, Paper 89-1E, p.251-256.

JACKSON, L.E. JR., BARENDREGT, R., IRVING, E., and WARD, B. 1990. Magnetostratigraphy of early to middle Pleistocene basalts and sediments, Fort Selkirk area, Yukon Territory. *In*: Current Research, Part E, Geological Survey of Canada, Paper 90-1E, p.277-286.

JACKSON, L.E. JR., and HARINGTON, R. 1991. Middle Wisconsinan Mammals, Stratigraphy, and Sedimentology at the Ketza River Site, Yukon Territory. Geographie physique et Quaternaire, 45: 69-77.

MATTHEWS, J.V. JR., SCHWEGER, C.E., and HUGHES, O.L. 1990. Plant and Insect Fossils from the Mayo Indian Village Section (Central Yukon): New Data on Middle Wisconsinan Environments and Glaciations. Geographie physique et Quaternaire, 44: 15-26.

McCONNELL, R.G. 1901. Exploration of Tintina Valley from the Klondike to Stewart River. Sum. Rept. for 1900. *In:* Yukon Territory, Selected Field Reports of the Geological Survey of Canada 1898 to 1933., Bostock, H.S. (ed.) Geological Survey of Canada, Memoir 284, pp. 26-29.

MCNEELY, R. 1991. Geological Survey of Canada radiocarbon dates XXIX. Geological Survey of Canada, Paper 89-7, 134 p.

MORISON, S.R. 1983. Placer deposits of Clear Creek drainage basin, 115P, central Yukon. *In:* Yukon Exploration and Geology 1983, Exploration and Geological Services Division, Northern Affairs Program, Yukon Region, p. 88-93.

MURPHY, D.C. and HEON, D. 1994. Geological overview of Sprague Creek map area, western Selwyn Basin. *In:* Yukon and Exploration and Geology 1993; Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 29-46.

OSWALD, E.T. and SENYK, J.P. 1977. Ecoregions of Yukon Territory. Fisheries and Environment Canada, 115p.

RUTTER, N.W., FOSCOLOS, A.E., and HUGHES, O.L. 1978. Climatic trends during the Quaternary in central Yukon based upon pedological and geomorphological evidence; *In:* Quaternary Soils, W.C. Mahaney (ed.); Geo Abstracts, Norwich, England, p. 309-359.

SMITH, C.A.S., TARNOCAI, C., and HUGHES, O.L. 1986. Pedological Investigations of Pleistocene Glacial Drift Surfaces in the Central Yukon. Geographie physique et Quaternaire, 1986, vol. XL, no. 1, p. 29-37.

TARNOCAI, C., SMITH, C.A.S., and HUGHES, O.L. 1985. Soil Development on Quaternary deposits of various ages in central Yukon Territory. *In:* Current Research, Part A. Geological Survey of Canada Paper 85-1A: 229-238.

TARNOCAI, C., and SMITH, C.A.S. 1989. Micromorphology and development of some central Yukon paleosols, Canada. Geoderma, 45: p. 145-162.

TARNOCAI, C., and SCHWEGER, C.E. 1991. Late Tertiary and early Pleistocene paleosols in northwestern Canada. Arctic, 44: 1-11.

TEMPLEMAN-KLUIT, D.J. 1979. Transported Cataclastic, Ophiolite and Granodiorite in Yukon: Evidence of Arc-Continental Collision. Geological Survey of Canada, Paper 79-14, 27 p.

TEMPLEMAN-KLUIT, D. 1980. Evolution of Physiography and Drainage in Southern Yukon. Canadian Journal of Earth Sciences, 17: 1189-1203.

VERNON, P. and HUGHES, O.L. 1966. Surficial geology, Dawson, Larsen Creek, and Nash Creek map-areas, Yukon Territory (116B and 116C east half, 116A and 106D). Geological Survey of Canada, Bulletin 136, 25p.

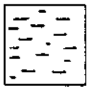
WAHL, H.E., FRASER, D.B., HARVEY, R.C., and MAXWELL, J.B. 1987. Climate of Yukon. Climatological Studies, Number 40. Environment Canada, Atmospheric Environment Service, 323p.

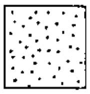
WARD, B.C. 1993. Quaternary Geology of Glenlyon Map Area (105L), Yukon Territory. Unpublished Ph.D. thesis, Department of Geology, University of Alberta, Edmonton, Alberta.

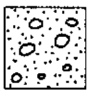
WARD, B.C., and JACKSON, L.E. Jr. 1992. Late Wisconsin glaciation of the Glenlyon Range, Pelly Mountains, Yukon Territory, Canada. Canadian Journal of Earth Sciences, 29: 2007-2012.

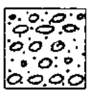
ZOLTAI, S.C., and TARNOCAI, C. 1974. Perennially frozen peatlands in the western Arctic and subarctic of Canada. Canadian Journal of Earth Science, vol. 12, p.28-43.

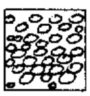
APPENDIX A: LEGEND FOR VERTICAL LITHOSTRATIGRAPHIC LOGS

 Clays and Silts

 Sands

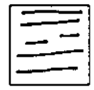
 Pebbly Sands

 Matrix-filled gravels

 Openwork gravels

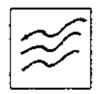
 Diamicton

 Ice or Sand wedge

 Planar stratification

 Trough cross-stratification

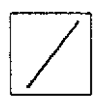
 Planar cross-stratification

 Depositional stoss climbing ripples

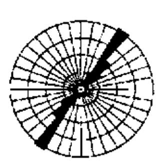
 Sediment gravity flow

 Lenses

 Organics

 Fault

x	Radiocarbon date
Cl	Clay
Si	Silt
Sa	Sand
G	Granules
P	Pebbles
C	Cobbles
B	Boulders

 Rose diagram of diamicton fabric

NATURAL REVEGETATION OF PLACER MINE TAILINGS NEAR MAYO, CENTRAL YUKON

C.E. Wilson[1], T.C. Hutchinson[1] and C.R. Burn[2]

Wilson, C.E., Hutchinson, T.C., and Burn, C.R. 1996. Natural revegetation of placer mine tailings near Mayo, Central Yukon. *In*: LeBarge W.P. (ed.), 1996. Yukon Quaternary Geology Volume 1, Exploration and Geological Services Division, Northern Affairs Program, Yukon Region, p. 47-62.

Abstract

Placer mining occurs extensively in parts of the Yukon, denuding riparian zones and lining valley bottoms with mine tailings. Revegetation of tailings was examined at two placer mines near Mayo to determine the influence of environmental variables on the speed and direction of the natural process. Vegetation species density and frequency on various substrates were compared with: age, slope and aspect of the site, and pH, particle size distribution, moisture content and organic content of the soil. In central Yukon, tailings are first colonized by ruderal (weedy pioneer) species such as fireweed and members of the Compositae (dandelion) family. These are replaced by willow-dominated communities after nine years. Willow communities support many species characteristic of the adjacent undisturbed black spruce forest, suggesting that the placer succession is similar to that of riverbank environments in interior Alaska. Revegetation of the tailings proceeds at the same rate for the first twelve years as does that following natural disturbance. Of the environmental factors examined, only age and slope were, statistically, associated with rate of revegetation. Both the percent cover and the number of species at a site were inversely associated with slope, suggesting that reduction of slope angle enhances vegetation regeneration.

[1] Environment and Resource Studies Program, Trent University, Peterborough, Ontario K9J 7B8.

[2] Department of Geography and Ottawa-Carleton Centre for Geoscience Studies, Carleton University, 1125 Colonel By Drive, Ottawa, Ontario K1S 5B6.

[2] Corresponding author

Introduction

The placer mining industry continues to play an important role in the Yukon economy, and operates in a society where environmental awareness is growing. Recent studies in other parts of Canada have tested ways to facilitate the revegetation of chemically-contaminated mine tailings, but few have investigated the natural revegetation of non-toxic placer tailings.

Placer mining is a highly mechanized industry which can cause the re-routing of rivers and streams and can move considerable soil, gravel, rock and vegetation in the valleys mined. Vegetation and topsoil are removed from parts of the valley, and as the underlying auriferous gravels are excavated and processed, tailings piles are left behind. The tailings consist of washed gravel, from which gold has been recovered, and are not chemically toxic. They do, however, occupy ground which would previously have supported riparian (riverbank) vegetation, and are generally covered by little top soil. They are often nutrient impoverished and drought-prone because of their coarse particle size.

Riparian vegetation is of importance to many animals and helps maintain physical and chemical balances in the floodplain environment (Deans, 1992). Riparian zones, commonly comprising willows and alders, are feeding grounds for moose, rabbits, grouse, ptarmigan, passerine birds and mice. The vegetation retards erosion and can form river overhangs, both of which are important for fish habitat, and are a source of organic matter for the aquatic food chain (Deans, 1992; Cooper and van Haveren, 1994). The replacement of riparian plant communities with piles of bare placer tailings has been shown to increase the sediment load of streams, which has a negative impact on fish and invertebrate populations (Wagener and LaPerriere, 1985; McLeay et al., 1987).

It is desirable to encourage the re-colonization of placer tailings by riparian vegetation, in order to facilitate the re-establishment of the natural ecology of the valley bottom following mining. Yukon placer mining policy, governed by the federal Department of Indian Affairs and Northern Development, currently requires miners to meet strict guidelines on sediment discharge levels into streams (Placer Mining Section, 1993). In some areas miners are also required to do reclamation work, such as grading slopes and spreading topsoil, although there has not historically been legislation governing land use practices on placer or hardrock mining claims. Mining land use regulations, which address the restoration of terrestrial ecosystems after mining, are under development and are scheduled to affect placer mining beginning in 1997 (D. Latoski, pers.comm., 1996). This study examines the revegetation occurring naturally on placer tailings at two mines in central Yukon to further understand the process. The objectives of this paper are: (1) to compare natural revegetation on placer tailings in the Mayo District with natural riparian succession at sites in Alaska; and, (2) to determine the relation between various environmental factors and the recolonization sequence.

Study Area

The Mayo area lies in the northern boreal forest and in the widespread permafrost zone. To the north the region includes dissected terrain of the southern Wernecke Mountains, but the remainder comprises tablelands intersected by broad valleys. The area was near the edge of the Cordilleran ice sheet during the most recent (McConnell) glaciation, and higher ground was ice-free (Figure 1).

The climate of the area is sub-arctic continental, with warm summers and long, cold winters, especially in valley bottoms. Mean annual temperature and precipitation at Mayo (504 m a.s.l.) are -4.0°C and 306 mm respectively. Mean July temperature and precipitation are 15.2°C and 52 mm, but at Keno Hill (1472 m a.s.l.) the values are 10.0°C and 56 mm respectively. Growing conditions deteriorate with elevation, such that treeline on north- and south-facing slopes is at approximately 1200 m and 1400 m a.s.l.

Large portions of the region are underlain by permafrost, particularly where a thick moss cover has grown. The impedance to drainage provided by permafrost, and the regular occurrence of near-surface ground ice combine to create moist forest soils during the thaw season.

The bedrock is quartzite, meta-sandstone phyllite and schist of late Paleozoic age, which is cut by quartz-siderite veins containing argentiferous galena, tetrahedrite, pyrargyrite and native silver (Murphy and Roots, 1992). Mining of these silver-rich veins began in 1913 and has continued to the present day.

A large amount of the region is covered by a veneer of Quaternary drift, and gold placers are regularly found close to bedrock.

Duncan Creek

Gold has been mined on Duncan Creek since 1898. The entire creek was staked by 1902, but following an initial rush, activity peaked in 1903 (Mayo Historical Society, 1991). There was sporadic mining before the second World War. The longest running placer operation on Duncan Creek is operated by the Taylor family, who began mining there in 1958. Their ground was worked by others in the 1920s, and

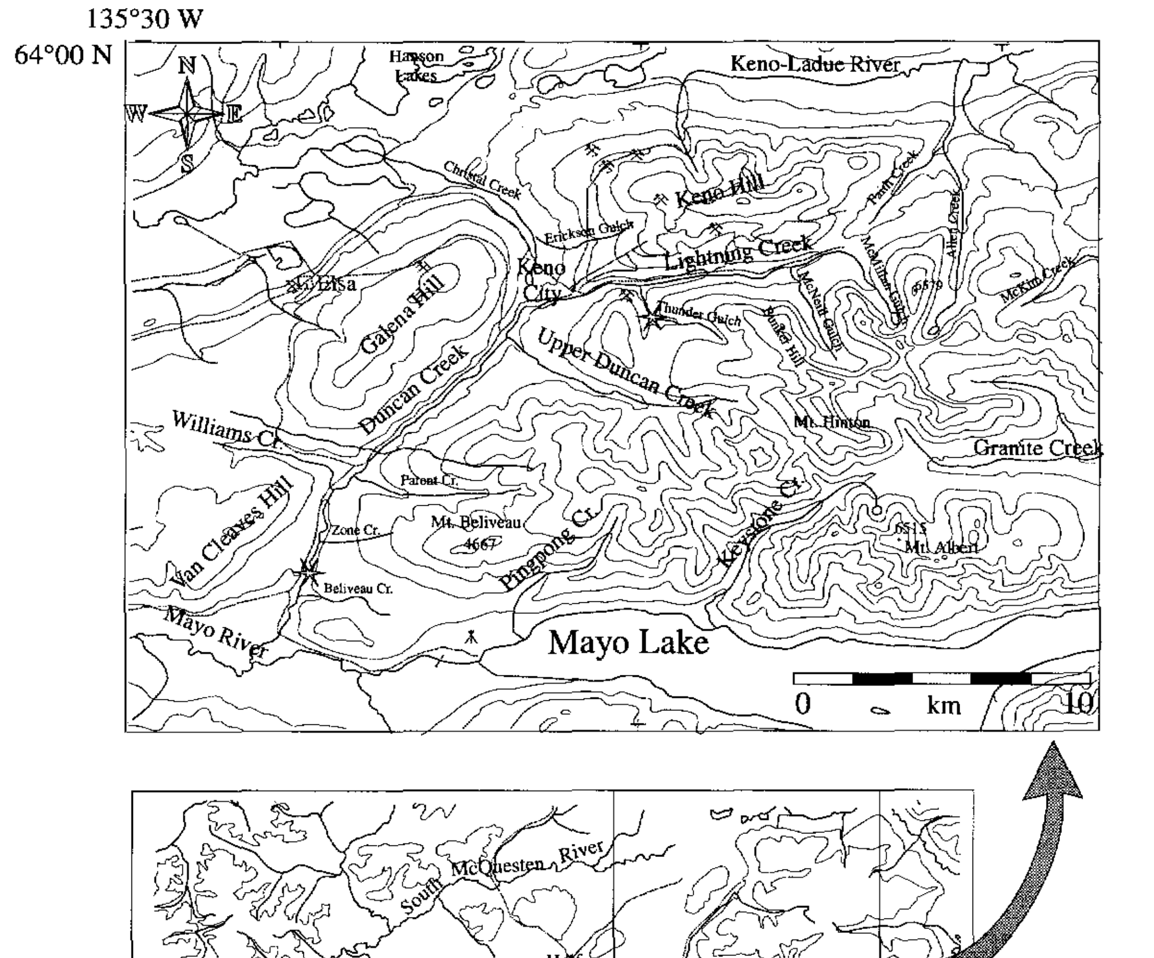


Figure 1: Location Map showing tailing sites on Duncan Creek and Thunder Gulch.

provides several of the sites examined in this study. The mine is at 750 m a.s.l., on a site which was covered by ice during McConnell glaciation. The undisturbed vegetation is black spruce forest, with extensive, thick, feathermoss ground cover.

Thunder Gulch

Thunder Gulch has not been glaciated since the Reid episode (greater than 200,000 years), but glacial material accumulated in the valley bottom both during earlier glaciations and by downslope movement during the McConnell period. Thunder Gulch has been staked since 1910, but is hard to mine because of large boulders and thick drift cover (Mayo Historical Society, 1991). These factors discouraged early miners, but modern equipment was used recently by the Barchen family for several years (Placer Mining Section, 1993). The tailings are at elevations between 1050 m and 1200 m a.s.l., on the north side of Gustavus Range (Figures 2A, 2B). The undisturbed vegetation includes scattered spruce trees with a ubiquitous ground cover of dwarf birch underlain by mosses.

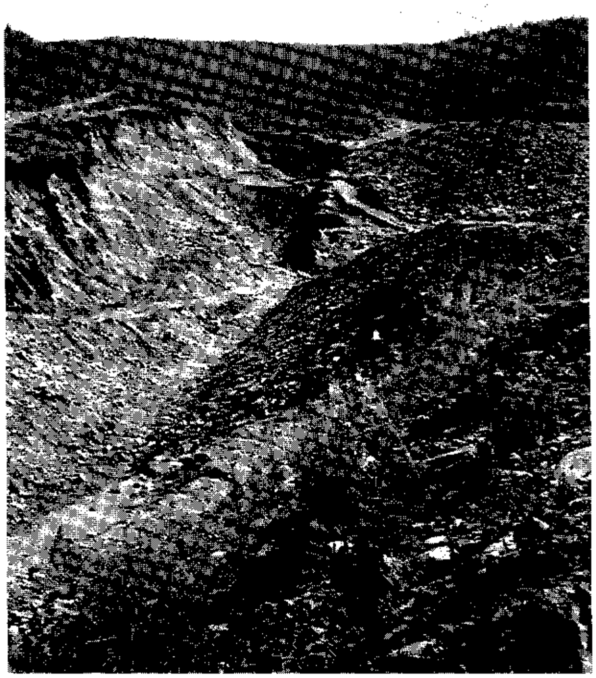


Figure 2A: View looking north up Thunder Gulch shows placer mine tailings in the valley center.

Figure 2B: Abandoned mining section exposed along Thunder Gulch shows glacial sediments which overlie the pay gravels. Glaciers have not been active in the valley for over 200,000 years.

Field and Laboratory Methods

Sites

Twenty-two sites were studied, fifteen of which are on tailings. The remaining seven are undisturbed sites immediately adjacent to the tailing sites on similar landform and position, for comparison as well as to provide a general account of vegetation in the area. Nine of the fifteen tailings sites and five of the seven undisturbed study sites are located along Duncan Creek, with the remainder at Thunder Gulch. The tailings sites were chosen to represent a range of ages; the approximate ages of the tailings were provided by local miners. The slope angle and aspect of each site were measured with a Brunton compass.

Vegetation Description

Each site was first delineated as a representative area of approximately 20 x 20 m, within which a complete plant species list was compiled using field guides (Trelawney, 1988; Pratt, 1991). A series of adjacent quadrants of increasing size (starting at 1 x 1m) were laid out to assess the abundance and distribution of each species, until all species on the master list had been encountered. Each species was then assigned a cover and importance value according to the Domin scale (Kershaw, 1973). Voucher specimens were collected and pressed. Most plant species were identified using Hulten (1968), and Conrad (1970) and Lawton (1971) for the cryptograms. However, some difficult grasses and willows were only recorded as genera. Common names are used in the text wherever possible, accompanied by their Latin binomials upon first mention. A complete list of the common names and their corresponding Latin binomials is provided in Appendix 1.

Site Legend (D = Duncan Creek, T = Thunder Gulch)																						
Species Present (>2 Domin Scale)	Tailings in Ascending Order of Approximate Age (Years)															Undisturbed Sites						
	0	1	2	3	3	4	4	5	9	9	9	10	12	65	65							
	(T)	(D)	(D)	(T)	(T)	(D)	(T)	(T)	(T)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(T)	(T)	(D)	(D)	(D)
HERBS																						
Swamp cranberry		X																			X	
Tumble mustard				X					X													
Arctic Wormwood							X															
Bent grass							X		X											X		
Dwarf fireweed		X				X				X			X	X								
Blue fleabane				X		X			X				X	X								
Elegant hawksbeard			X	X		X						X										
Fireweed				X			X		X		X							X				
Arctagrostis grass						X							X	X								
Reed grass										X							X	X			X	X
Mountain fleabane											X											
Gentian											X											
Grass of Parnassus														X								
Alkali grass											X					X						
Wild sweet pea											X					X						
Horsetail													X	X			X	X		X		
Bastard toadflax																X	X					X
Alpine bistort																		X				
Cloudberry																			X			
Arctic sweet coltsfoot																			X			
SHRUBS																						
Shrubby Cinqefoil											X				X							
Red raspberry												X										
Labrador tea											X				X	X	X	X	X	X	X	X
Cherry willow											X					X	X					
Barclay willow										X	X					X	X					
Silver willow											X					X	X					
Felt leaf willow										X	X		X	X				X		X	X	
Pacific willow										X	X	X	X	X					X			
Unidentified willows										X				X				X			X	
Salix pulchra (willow)														X								X
Blue-green willow														X		X				X		
Mackenzie willow																			X			
Netted willow																X				X		
Richardson's willow																	X		X			
Bearberry																	X			X		X
Kinnickinnick																	X	X	X	X	X	
Crowberry																		X	X			
Dwarf birch																X	X	X	X		X	
Bog blueberry																X	X	X	X	X	X	X
TREES																						
Black spruce										X		X	X			X	X	X	X	X	X	X
Mountain alder										X	X		X	X			X		X			X
Trembling aspen										X		X	X									X
Paper birch																		X				
MOSSES AND LICHENS																						
Hylocomnium splendens											X				X		X					
Cladonia major															X	X	X	X				
Cladonia unicialis															X		X	X	X			
Cladonia plevrota															X			X				
Tomenthypnum nitens																	X	X	X	X	X	X
Sphagnum girgensohii																	X		X	X	X	
Plurozium schreberi																			X	X		X
Cladina rangiferina																				X	X	X
Aulacomium palustre																		X				
Total # of Species on Site	0	15	5	8	17	13	10	7	11	22	28	14	17	21	20	28	26	32	19	20	17	18

Table 1: Occurrence of plant species at each of the tailings and undisturbed sites, as recorded in the summer of 1994. This is based on Domin scale estimates, and only those of greater than 5% cover are included.

Soil Characteristics

One soil sample per site was collected from the uppermost 20 cm of mineral soil, and tested on-site for pH. In the lab, the moisture content of each sample was determined by weight before and after oven-drying. Organic matter content was estimated by loss of weight on ignition (for 8 h at 350°C) in a muffle furnace. To determine particle-size distribution, soil samples were first passed through a 2 mm sieve and the fraction caught was called gravel (>2 mm). The proportions of sand (50 microns - 2 mm) and silt and clay (<50microns) in the <2 mm fraction that passed through the sieve were determined by the pipette method, with the sand initially isolated by 50 micron sieve (Gee and Bauder, 1982).

Results

Vegetation Description

Species compositions of the vegetation communities present on the tailings and undisturbed sites are compared in Table 1. All species present with a Domin value of two or more are listed against sites in ascending order of age. The vegetation composition on the tailings changes after approximately nine years and the succession can be described as two stages.

The initial, sparse cover which becomes established during the first nine years after deposition of the tailings includes ruderal pioneer species, often with small, wind-dispersed seeds. It includes fireweed (*Epilobium angustifolium*), dwarf fireweed (*E. latifolium*), tumble mustard (*Sisymbrium altissimum*),blue fleabane (*Erigeron acris*), swamp cranberry (*Oxycoccus microcarpus*), arctic wormwood (*Artemesia arctica*), elegant hawksbeard (*Crepis elegans*), arctagrostis grass (*Arctagrostis poaeoides*), and bent grass (*Agrostis* sp.).

After nine years, arctic wormwood, swamp cranberry, tumble mustard, and bent grass have been replaced, while fireweed and elegant hawksbeard are less frequent. The remaining species are joined by labrador tea (*Ledum palustre*), wild sweetpea (*Hedysarum mackenzii*), shrubby cinquefoil (*Potentilla fruticosa*), raspberry (*Rubus idaeus*), mountain fleabane (*Erigeron humilis*), grass of parnassus (*Parnassia palustris*), gentian (*Gentiana* sp.), reed grass (*Calamagrostis* sp.), alkali grass (*Puccinellia* sp.), and horsetail (*Equisetum* sp). The most characteristic aspects of this later revegetation stage are the abundance of willows, particularly felt-leaf willow (*S. alaxensis*) and pacific willow (*S. lasiandra*), and the appearance of tree seedlings, mosses and lichens. Tree seedlings include black spruce (*Picea mariana*), mountain alder (*Alnus crispa*) and trembling aspen (*Populus tremuloides*). The ground cover consists of the feathermoss *Hylocomnium splendens*, and three lichen species; *Cladonia major*, *C. unicialis*, and *C. pleurota*.

As this older willow-dominated vegetation type gradually replaces the communities initially established on the tailings, many of the new species moving in (ie. all of the tree seedlings, willows, mosses and lichens, as well as labrador tea, wild sweet pea, reed grass, alkali grass and horsetail) are the same species found on the undisturbed sites.

The undisturbed sites support significantly more species than the tailings sites (see Table 1 for a more complete list), and can be characterized as black spruce stands, although mountain alder, trembling aspen and paper birch (*Betula papyrifera*) are also seen occasionally. Many willows join dwarf birch (*Betula nana*) in forming the shrub understory. Bog blueberry (*Vaccinium uliginosum*) and labrador tea are the dominant sub-shrubs, but kinnickinnick (*Arctostaphylos uva-ursi*), bearberry (*A. Rubra*) and northern comandra (*Geocaulon lividum)* are also common. The most common herb observed was horsetail. The ground cover is dominated by the mosses *Tomenthypnum nitens*, *Sphagnum girgensohii*, *Plurozium schreberi* and various lichens of the *Cladonia* genus.

The vegetation pattern appears to develop in a continuum, from the youngest tailings through to the undisturbed sites, and suggests a three-stage successional sequence, from the initial herbaceous ruderal cover to willow communities to black spruce stands. The latter may be considered the natural climax vegetation for the area.

Environmental factors

The following results were calculated for the tailings sites only, with the undisturbed communities included for comparison where appropriate.

The amount of ground covered by vegetation (percent cover), and number of species present were the variables used to represent vegetation at a given site. Coefficients of linear correlation for these variables with site and soil characteristics measured are presented in Table 2.

Slope

As shown in Table 2, slope is the environmental factor which is most correlated with both number of species (r=-0.78) and percent cover (r=-0.82) at the sites. Both percent cover and number of species decrease with increasing slope angle (see Figures 3 and 4).

	Number of Species	Percent Cover
Site Characteristics		
Slope (%)	-0.78**	-0.82**
Age	0.42	0.56*
Aspect	0.03	0.37
Soil Characteristics		
Organic matter (%)	0.54*	0.35
Moisture (%)	0	-0.27
Gravel (% >2mm)	0.12	0.14
Sand (% 50μ - 2mm)	0.01	0.07
Silt and Clay (% < 50μ)	-0.04	-0.06
pH	-0.08	-0.02

Correlation coefficients (r values) followed by * are significant at p=0.05, and ** are significant at p=0.01

$r_{0.05(2),12}=0.53$

$r_{0.01(2),12}=0.66$

Table 2: Pearson correlation for either number of plant species or percent cover per site plotted against various site and soil characteristics.

	0 - 9 Years	9 - 65 Years	Undisturbed
Number of Species	10 ± 5	20 ± 5	23 ± 6
Percent Cover	23 ± 18	62 ± 24	100 ± 0

Table 3: Number of species and percent cover on tailings of different ages (means + one standard deviation, rounded to the nearest whole number).

	Mean ± One Standard Deviation	
Particle Size Distributions	Tailings	Undisturbed
% Gravel (>2mm)	58.1± 10.9	6.7 ± 9.2
% Sand (50μ - 2mm)	31.4 ± 9.8	23.9 ± 11.7
% Silt and Clay (<50μ)	10.5 ± 8.8	69.4 ± 15.5
Other Soil Properties		
% Organic	3.1 ± 5.0	17.6 ± 9.9
% Moisture	5.6 ± 5.0	36.7 ± 15.9
pH	6.6 ± 0.5	6.3 ± 0.6

Table 4: Soil properties of tailings and undisturbed sites.

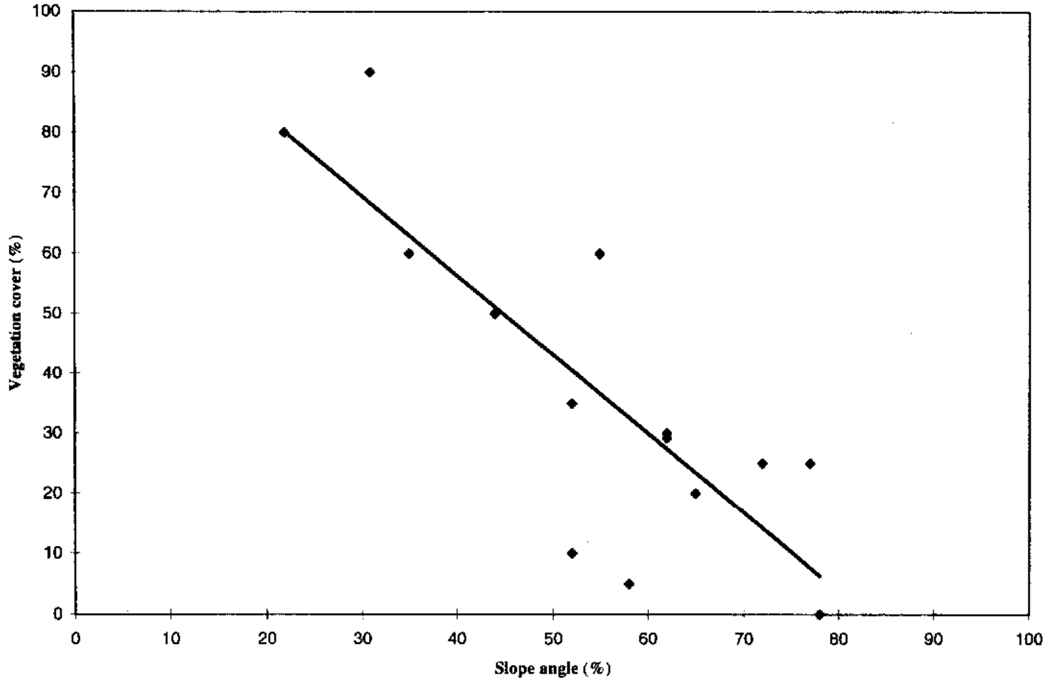


Figure 3: Slope angle of tailings vs. vegetation cover

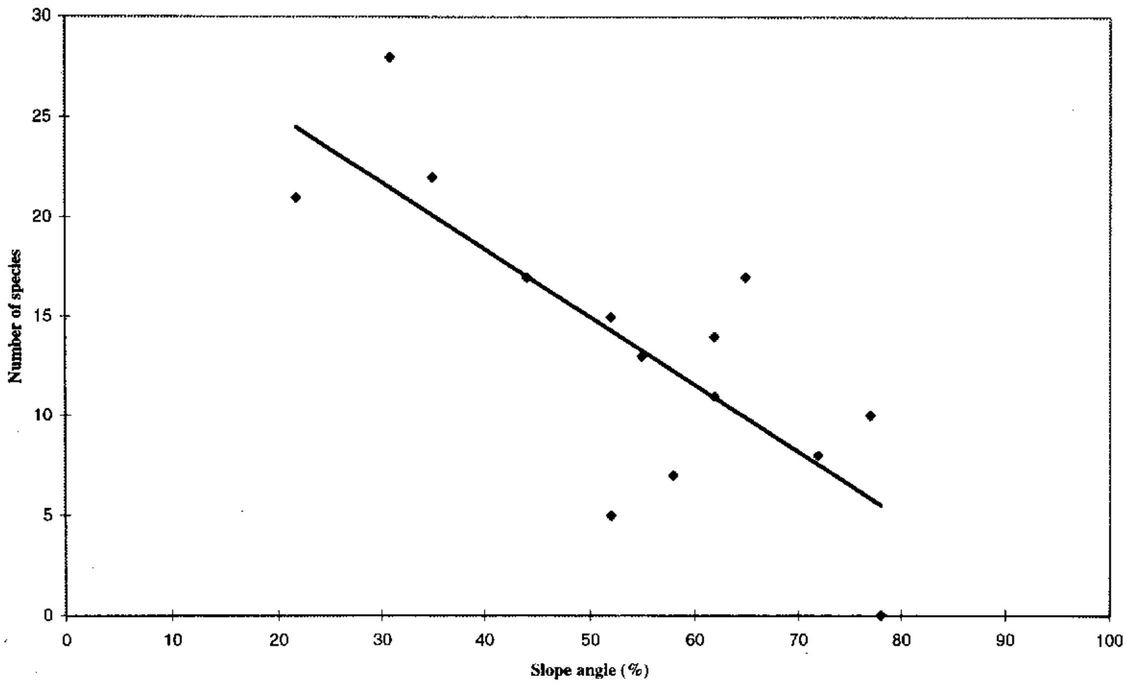


Figure 4: Slope angle of tailings vs. number of plant species present

Age

Age of tailings was correlated with vegetation characteristics, although there was a better correlation with percent vegetation cover (r=0.56) (Figure 5) than with number of species (r=0.42). The suggestion of a relation between age and revegetation is supported by a comparison of means. Table 3 shows the tailings sites divided into the two age groups, which are suggested by changes in species composition (Table 1) along with the respective means and standard deviations for percent cover and number of species. Undisturbed sites are also included for comparison. The older group of tailings sites has significantly more species and ground cover than the younger tailings, and less ground cover than the undisturbed sites. Differences in the number of species on older tailings and undisturbed sites were not significantly different under a two-sided t-test.

Aspect

Aspect was not significantly correlated with either the number of species or percent vegetation cover (Table 2).

Soil Properties

Organic matter was the soil property most strongly correlated with both number of species (r=0.54) (Figure 6) and percent vegetation cover (r=0.35), and was the only soil property to show a statistically-significant correlation with vegetation (Table 2). When soil properties were plotted against age of the tailings, no statistically-significant relations were observed to suggest soil changes over time.

The soil properties of the tailings are compared to those of the undisturbed sites in Table 4. Each soil property is expressed as a mean, with standard deviations also provided. Tailings comprise significantly more gravel and sand, and less silt and clay, organic matter and moisture than undisturbed soils. Tailings did not differ significantly in pH (6.56 ± 0.50) from undisturbed sites (6.30 ± 0.63).

Discussion

Succession, or changes in vegetated communities over time, can be either primary or secondary. Primary succession occurs on surfaces which have not previously been vegetated, such as those resulting from the retreat of a glacier or fresh floodplain sediments. Secondary succession occurs on disturbed terrain where vegetation has been completely or partially removed, but where well-developed soil, seeds and spores remain intact (Begon et al., 1990; Deans, 1992). This study is concerned with primary succession as placer mine tailings generally consist of exposed gravels from which soil has been removed during sluicing (Deans, 1992).

Vegetation Description

Succession on floodplains has been studied extensively in Alaska, and a series of models has been proposed to describe various stages in the process (Drury, 1956; Bliss and Cantlon, 1957; Walker et al., 1986; Viereck, 1970). These models are based on an original proposal by Péwé which shows vegetation changes starting at the edge of a river and moving inland, through increasingly older terrain (Drury, 1956; Deans, 1992). Generally, the first stage of colonization on bare silt or gravel is by light-seeded ruderal herbs or shrubs, followed by willows and slower-growing balsam poplar (*Populus balsamifera*) seedlings. Within 10-15 years, the balsam poplar overtop the willows, which are replaced by prickly rose (*Rosa acicularis*) and high bush cranberry (*Viburnum edule*). Horsetail species provide ground cover, and white spruce (*Picea glauca*)becomes established. White spruce, often joined by paper birch, eventually replaces the poplars, and a thick feathermoss layer forms on the ground. As permafrost develops under the moss layer, black spruce gradually replaces white spruce and *Sphagnum* moss becomes established (Figure 7).

The first type of community to become established on the tailings in this study is comparable to the Perennial Herb Community described by Bliss and Cantlon (1957) and the Vegetated-Silt stage described by Walker et al. (1986). The Perennial Herb Community includes alpine hawksbeard (*Crepis nana),* riverbank fleabane (*Erigeron purpuratus),* dwarf fireweed, three wormwood species and a variety of legumes. This is similar to the community identified near Mayo, which included elegant hawksbeard, blue fleabane, dwarf fireweed, and arctic wormwood. Furthermore, the plants observed were small, which corresponds with the description of vegetation less than 0.6 meters tall (Walker et al., 1986).

All of the species characteristic of the Perennial Herb Community, other than dwarf fireweed and the legumes, are of the Compositae family (Hulten, 1968) which are weedy species capable of producing large amounts of small, highly wind dispersed, parachute assisted seeds. Dwarf fireweed is also known for its ability to quickly recolonize areas after disturbance, especially after forest fires (Pratt, 1991). The plants observed on the younger group of tailings also produce small, dispersable seeds, and prefer open habitats.

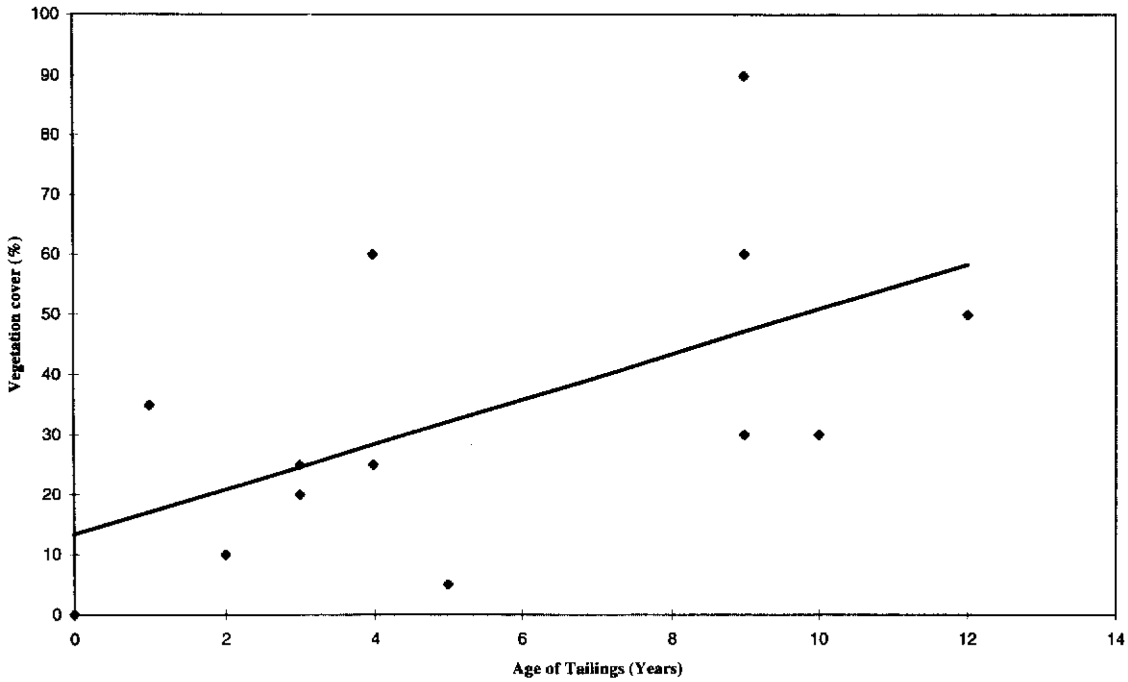


Figure 5: Age vs. vegetation cover for tailings between 0-12 years old

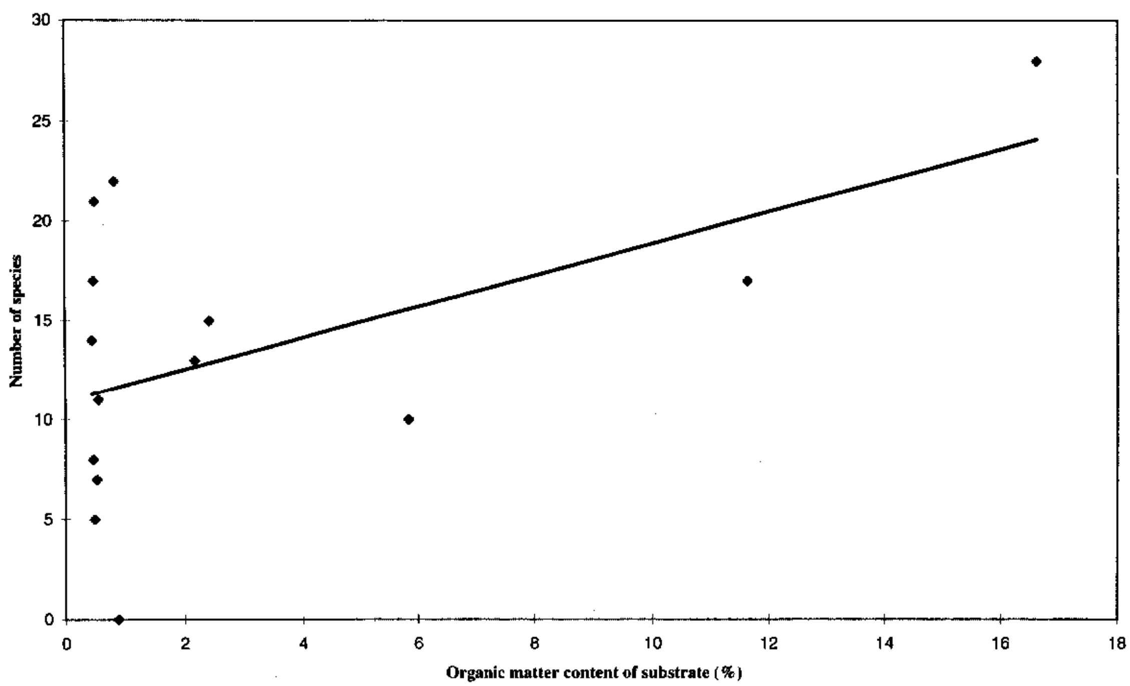


Figure 6: Organic matter content of tailings vs. number of plant species present

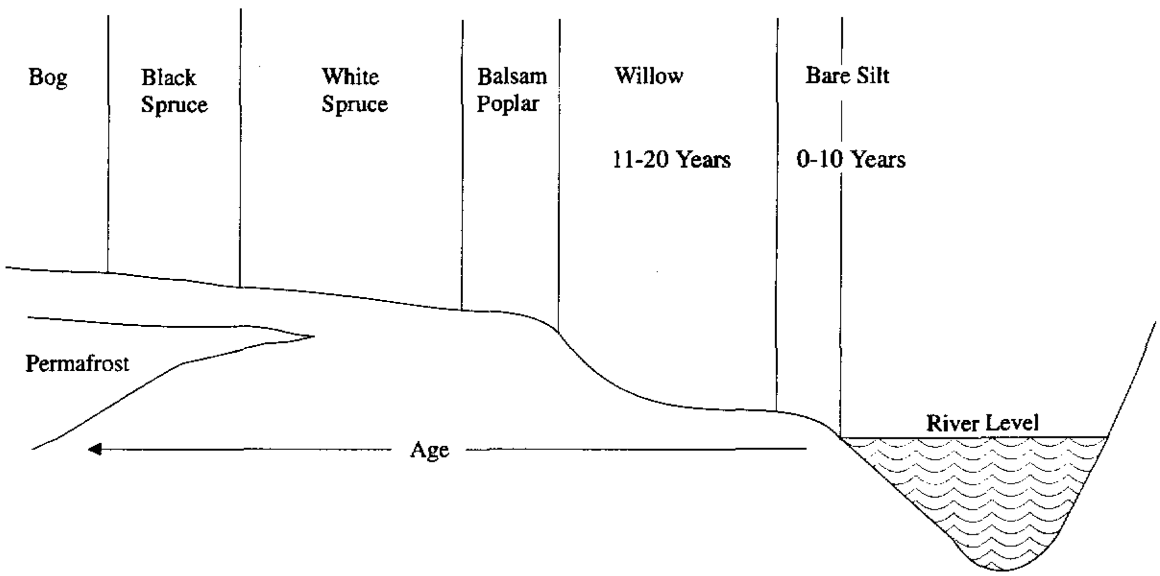


Figure 7: Diagram of the general relation between vegetation, age, permafrost and lateral distance from the river in interior Alaska (Viereck, 1970)

This early successional stage occurs in Alaska 6-10 years after disturbance (Walker et al., 1986). In central Yukon, the tailings supporting these communities were up to nine years old, indicating congruence between the recovery from natural and artificial disturbances. Some willows, mosses and lichens become established during this stage in Alaska (Bliss and Cantlon, 1957), and were observed on tailings 9-10 years old at the Yukon sites as the vegetation makes the transition to a willow stage (Table 1). Species noted in the full Alaskan willow stage were observed at Duncan Creek and Thunder Gulch.

The willow stage evolves in Alaska when the surface is 11-20 years old (Bliss and Cantlon, 1957; Walker et al., 1986). The tailings in this group at the study sites ranged from 9-12 years old. Interestingly, the species composition on the two 65-year old sites also fell into the willow category. At the Yukon study sites there were no balsam poplar or white spruce stages of floodplain succession described for Alaska (Figure 7).

The undisturbed sites indicated in Table 1 correspond to the black spruce stage of the successional sequence described for Alaska (Viereck, 1983). Dominated by black spruce, they also support willows, bog blueberry and Labrador tea. The extensive ground cover of mosses and lichens consists mainly of feathermosses. The presence of feathermosses suggests an age of at least 60 years (Viereck, 1983).

In summary, the sites observed in this study, both tailings and undisturbed, represent three of the five stages expected for natural floodplain succession in interior Alaska. In terms of species composition and time, natural revegetation on the placer tailings follows the expected course for at least the first twelve years. The absence of the balsam poplar and white spruce stages, together with the significant number of shared species between older tailings and adjacent undisturbed sites, suggests a three-stage succession in the Mayo District, with the willow stage as the only transition between initial colonization of the tailings and mature black spruce stands. This is consistent with two 65 year old sites being still in the willow stage. These observations may result from washed tailings being devoid of soil and seed banks with the disturbed site being dependent upon the black spruce forest as the primary seed source for revegetation.

Environmental Factors

Slope

Slope angle can affect revegetation through its control of solar radiation, drainage and site stability. Slope conditions ideal for rapid revegetation are nearly flat, with some surface roughness (Bramble, 1952; Deans, 1992). The slopes of large tailings piles are generally steep. Steepness can be compensated for by substrate composition, and stable shales as steep as 70% have been experimentally replanted with success (Bramble, 1952; Deans, 1992). The relation between slope angle and revegetation is clear in this study (Figure 3), with slope being the factor most clearly associated with number of species and percent cover at the sites. While more gradual slopes may enhance recolonization by reducing erosion, the greatest effect may be on water availability. As well as retaining more surface water, the surface of gradual slopes is likely to be closer to the water table (Cooper and van Haveren, 1994), making a more suitable environment for vegetation growth.

Age

Intuitively, age should be correlated with revegetation when the discussion is framed by the concept of succession. However, many studies have suggested it is not as important as other factors, particularly soil texture (Deans, 1992). After disturbance, favorable sites tend to be colonized rapidly while hostile sites may remain unvegetated for years. However, in this study, both percent cover and number of species were observed to increase with age of the tailings. Age was more strongly correlated with percent cover than any other variable, aside from slope (Table 1).

Aspect

Slopes of different aspects often support very different plant communities due to their differing receipt of solar radiation. However, no significant differences in vegetation relative to aspect were found in this study. The sample size was small, and sites were unevenly distributed among the four aspects.

Soil properties

The soil at a site is important to plant productivity, as it affects moisture and nutrient availability, site stability and temperature (Begon et al., 1990). Tailings present a challenge to colonizing plants as they generally consist of coarse particles and little organic matter and, therefore, are of low moisture content and nutrient status.

Tailings studied in Alaska contained between 20-50% soil (< 2mm), mostly sand, rather than silt or clay (Bramble, 1952; Deans, 1992). The tailings sampled near Mayo comprised, on average, 42% soil, of which 75% was sand. Soil texture has been shown to be an important factor in the revegetation of disturbed lands: vegetation cover on dredge-mine tailings in Alaska increased with higher proportions of silt and clay (Holmes, 1982; Deans, 1992).

Soil organic matter content is directly associated with soil fertility and water availability, and has been found to affect revegetation. A study on disturbed taiga in Alaska suggested that soil lacking organic material takes longer to recover from disturbance (Van Cleve, 1975; Deans, 1992). Organic layers are important to plants as a source of nutrients, of viable root stock (Deans, 1992), and of seeds (Chapin and Chapin, 1980). They also help to increase water retention and site stability (Viereck, 1970; Chapin and Chapin, 1980). The soil organic content at the sites studied near Mayo, on average 3%, is quite low.

Moisture content of the tailings was low, 6% on average, as expected from the lack of fine particles and organic matter. Moisture content has been suggested as the most important limiting factor in the revegetation of placer mine tailings and is often linked to height above the water table (Cooper and van Haveren, 1994). While riparian vegetation is adapted to colonize coarse gravel surfaces with low organic matter which are often left bare by stream movements, the process is dependent on shallow water tables and periodic flooding (Densmore et al., 1987; Bishop and Chapin, 1989a). This was illustrated in attempts to revegetate abandoned gravel pads in Alaska with riparian species, where the substrate was readily colonized only where sufficient water was made available (Bishop and Chapin 1989b). Placer tailings are often piled high and are beyond the reach of water tables and flooding.

Deans (1992) emphasized that all environmental factors on tailings piles are interdependent and can compensate for one another. While the scope of this study did not allow for the statistical exploration of this suggestion, some examples from the data illustrate the point. One site which was just three years old supported 17 species, the same as observed at one of the undisturbed sites. In this case, unusually high proportions of fine particles (48% silt and clay), organic matter (12%) and moisture (16%) in the tailings compensated for age and a steep slope (65%).

Of the three sites which are nine years old, the two which support willow communities have slopes of 31% and 35%, while the other, which is still in the Herb stage is much steeper (62%).

Overall, the tailings are revegetating effectively, even though moisture and soil organic levels are low. There was no major difference between the two groups of sites studied at Duncan Creek and Thunder Gulch, with respect to environmental factors measured.

Conclusions

The following conclusions are drawn from the data presented:

(1) Placer mine tailings in the Mayo District revegetate naturally, within the same time-frame and with a species composition similar to that occurring after a natural disturbance. The successional pattern observed in this study appears to occur in three stages, two less than observed in natural successions in Alaska.

(2) Slope angle is the primary environmental factor affecting revegetation of placer tailings. Slope, and to a lesser extent, organic content of the soil had a greater influence on revegetation than age. This suggests that if placer tailings are to be rehabilitated with a view to re-establishing vegetation, slope and soil organic content will be important factors to consider. The speed of recolonization is also affected by seed source proximity. A thin layer of soil spread across the site may substantially accelerate the process.

Acknowledgements

Field and laboratory work reported in this paper were supported by a grant from the Northern Scientific Training Program (DIAND) through Trent University to C.E. Wilson, and by an NSERC Operating Grant to C.R. Burn. Access to tailings on Duncan Creek was by kind permission of Frank and Bonnie Taylor, and at Thunder Gulch by Hans and Gina Barchen. Field assistance from Brenda Sproule was greatly appreciated. Laboratory analyses were completed at J.V. Clark School, Mayo, and at Carleton University. The fieldwork for this study would not have been possible without the support, hospitality and friendship of many people in Mayo.

References

BEGON, M., HARPER, J.L., and TOWNSEND, C.R. 1990. Ecology: Individuals, populations and communities, 2nd. ed. Blackwell Scientific Publications, Boston.

BISHOP, S.C. and CHAPIN, F.S. 1989a. Establishment of Salix alaxensis on a gravel pad in arctic Alaska. Journal of Applied Ecology 26: 575-583.

BISHOP, S.C. and CHAPIN, F.S. 1989b. Patterns of natural revegetation on abandoned gravel pads in arctic Alaska. Journal of Applied Ecology 26: 1073-1081.

BLISS, L.C. and CANTLON, J.E. 1957. Succession of river alluvium in northern Alaska. The American Midland Naturalist 58: 452-469.

BRAMBLE, W.C. 1952. Reforestation of strip-mined bituminous coal land in Pennsylvania. Journal of Forestry 50: 308-314.

CHAPIN, F.S. and CHAPIN, M.C. 1980. Revegetation of an arctic disturbed site by native tundra species. Journal of Applied Ecology 17: 449-456.

CONRAD, H.S. 1970. The mosses and liverworts. W.C. Brown, Dubuque.

COOPER, D.J. and VAN HAVEREN, B.P. 1994. Establishing felt-leaf willow from seed to restore Alaskan, U.S.A., floodplains. Arctic and Alpine Research 26: 42-45.

DEANS, A. 1992. Environmental factors influencing the natural revegetation of placer mine tailings in interior Alaska. M.S. thesis, Colorado School of Mines, Golden.

DENSMORE, R.V., NEILAND, B.J., ZASADA, J.C. and MASTERS, M.A. 1987. Planting willow for moose habitat restoration on the north slope of Alaska, U.S.A. Arctic and Alpine Research 19: 537-543.

DRURY, W.H. JR. 1956. Bog flats and physiographic processes in the upper Koskokwim River region, Alaska. *In*: Contributions to the Gray Herbarium, R.C. Rollins and R.C. Foster (eds.). Harvard University, Cambridge, MA.

HULTEN, E. 1968. Flora of Alaska and neighboring territories. Stanford University Press, Stanford, California.

GEE, G.W. and BAUDER, J.W. 1982. Particle-size analysis. *In*: Methods of soil analysis - Part 1: Physical and mineralogical methods, A. Klute (ed.). Agronomy Monograph No.9 (2nd ed.) American Society of Agronomy - Soil Society of America, Maddison, Wisconsin. 331- 362.

KERSHAW, K.A. 1973. Quantitative and dynamic plant ecology, 2nd ed. William Clowes & Sons Ltd., London.

LAWTON, E. 1971. Moss flora of the Pacific Northwest. Hattori Botanical Laboratory, Miyazaki, Japan.

MAYO HISTORICAL SOCIETY. 1991. Gold and galena: a history of the Mayo District. Mayo Historical Society, Mayo. 502 p.

MCLEAY, D.J., BIRTWELL, I.K., HARTMAN, G.F., and ENNIS, G.L. 1987. Responses of arctic grayling (Thymallus arcticus) to acute and prolonged exposure to Yukon placer mining sediment. Canadian Journal of Fisheries and Aquatic Science 44: 658-673.

MURPHY, D.C., and ROOTS, C.F. 1992. Geology of Keno Hill Map Area 105M/14. Exploration and Geological Services Division, Yukon Region, INAC. Open File Map 1992-3.

PLACER MINING SECTION, 1993. Yukon Placer Mining Industry 1991-1992; Mineral Development Division, Yukon, Indian and Northern Affairs Canada, 145 p.

PRATT, V.E. 1991. Wildflowers along the Alaska Highway. Alaskakrafts Inc., Anchorage, Alaska.

TRELAWNEY, J.G. 1988. Wildflowers of the Yukon, Alaska and northwestern Canada. Sono Nis Press, Victoria, B.C.

VAN CLEVE, K. 1975. Recovery of disturbed tundra and taiga surfaces in Alaska. *In*: Recovery and restoration of damaged ecosystems, J. Cairns Jr., K.L. Dickson and E.E. Herricks (eds.). University of Virginia Press, Charlottesville, VA.

VIERECK, L.A. 1970. Forest succession and soil development adjacent to the Chena River in interior Alaska. Arctic and Alpine Research 3: 1-26.

VIERECK, L.A. 1983. The effects of fire in black spruce ecosystems of Alaska and northern Canada. *In*: The role of fire in northern circumpolar ecosystems, R.W. Wein and D.A. MacLean (eds.). John Wiley & Sons, New York. 201-220.

WAGENER, S.M. and LAPERRIERE, J.D. 1985. Effects of placer mining on the invertebrate communities of interior Alaska streams. Freshwater Invertebrate Biology 4: 208-214.

WALKER, L.R., ZASADA, J.C. and CHAPIN, F.S. III. 1986. The role of life-history processes in primary succession on an Alaskan floodplain. Ecology 67: 1508-1523.

Appendix 1: Common plant names and corresponding Latin binomials (Conrad 1970, Hulten 1968, Lawton 1971, Porsild and Cody 1980, Pratt 1991, Trelawney 1988)

Common Names	Latin names
TREES	
Balsam poplar	*Populus balsamifera* L.
Black spruce	*Picea mariana* (Mill.) Britt. Sterns&Pogg.
Mountain alder	*Alnus crispa* (Ait.) Pursh
Paper birch	*Betula papyrifera* Marsh.
Trembling aspen	*Populus tremuloides* Michx.
White spruce	*Picea glauca* (Moench) Voss
SHRUBS	
Barclay willow	*Salix Barclayi* Aderss.
Bearberry	*Arctostaphylos rubra* (Rehd. & Wilson) Fern.
Blue-green willow	*Salix glauca subsp. glabrescens* (Aderss.) Hult.
Bog blueberry	*Vaccinium uliginosum* L.
Cherry willow	*Salix padophylla* Rydb.
Crowberry	*Empetrum nigrum* L.
Dwarf birch	*Betula nana* L.
Felt leaf willow	*Salix alaxensis* (Anderss.) Cov.
Kinnickinnick	*Arctostaphylos uva-ursi* (L.) Spreng.
Labrador tea	*Ledum palustre* L.
Mackenzie willow	*Salix Mackenzieana* Barratt
Netted willow	*Salix reticulata* L.
Pacific willow	*Salix lasiandra* Benth.
Prickly rose	*Rosa acicularis* Lindl.
Red raspberry	*Rubus idaeus* L.
Richardson's willow	*Salix lanata* L.
Shrubby Cinqefoil	*Potentilla fruticosa* L.
Silver willow	*Salix candida* Flugge
Unidentified willows	*Salix* spp.
No common name	*Salix pulchra* Cham.
HERBS	
Alkali grass	*Puccinellia* spp. Parl.
Alpine bistort	*Polygonum viviparum* L.
Alpine hawksbeard	*Crepis nana* Richards.
Arctagrostis grass	*Arctagrostis poaeoides* Nash
Arctic sweet coltsfoot	*Petasites frigidus* (L.) Franch
Arctic wormwood	*Artemisia arctica* Less.
Bastard toadflax	*Geocaulon lividum* (Richards) Fern.
Bent grass	*Agrostis* spp. L.
Blue fleabane	*Erigeron acris* L.
Cloudberry	*Rubus chamaemorus* L.
Dwarf fireweed	*Epilobium latifolium* L.
Elegant hawksbeard	*Crepis elegans* Hook.
Fireweed	*Epilobium angustifolium* L.
Gentian	*Gentiana* spp. L.
Grass of Parnassus	*Parnassia palustris* L.
High bush cranberry	*Viburnum edule* (Michx.) Raf.
Horsetail	*Equisetum* spp. L.
Mountain fleabane	*Erigeron humilis* Graham
Reed grass	*Calamagrostis* spp. Adans.
Riverbank fleabane	*Erigeron purpuratus* Greene
Swamp cranberry	*Oxycoccus microcarpus* Turcz.
Tumble mustard	*Sisymbrium altissimum* L.
Wild sweet pea	*Hedysarum Mackenzii* Richards.
MOSSES AND LICHENS	
	Hylocomnium splendens (Hedw.) B.S.G.
	Cladonia major
	Cladonia unicialis
	Cladonia plevrota
	Homalothecium nitens (Hedw.) Robins.
Sphagnum moss	*Sphagnum girgensohii* Russow
	Pleurozium schreberi (Brid.) Mitt.
Reindeer moss	*Cladina rangiferina*
	Aulacomium palustre (Hedw.) Schwaegr.

SEDIMENTOLOGY AND STRATIGRAPHY OF DUNCAN CREEK PLACER DEPOSITS, MAYO, CENTRAL YUKON

William P. LeBarge[1]

LeBarge, W.P., 1996b. Sedimentology and stratigraphy of Duncan Creek placer deposits, Mayo, Central Yukon. *In*: LeBarge W.P. (ed.), 1996. Yukon Quaternary Geology Volume 1, Exploration and Geological Services Division, Northern Affairs Program, Yukon Region, p. 63-72.

Abstract

Placer deposits in the Mayo area occur in a wide variety of geomorphic settings, including alluvial fans, gulch gravels, valley-bottoms (alluvial plains), and bedrock terrace (bench gravel) settings which have been variably buried and reworked by glaciofluvial processes. Placer gold is also known to occur in glacial till and glaciofluvial gravels especially where these sediment types are close to bedrock.

Three major Quaternary glaciations (the pre-Reid, Reid and McConnell, in order of oldest to most recent) and their associated interglacials have modified the drainage and topography of this area, and these events have affected the formation, preservation and proportionate size of the District's placer gold deposits.

Duncan Creek, a tributary of the Mayo river which drains Mayo Lake, is one of the most actively-mined drainages in the Mayo District. Placer mining began in the Duncan Creek area in the early 1900's and has continued almost continuously to the present day. Gold production from Duncan Creek in the last 15 years has been nearly 20,000 crude ounces, with historical production estimated to be at least twice that for the last 95 years.

Although the McConnell ice limit only reached into the first few kilometres of the Duncan Creek valley at its mouth and at its headwaters, associated glaciolacustrine and glaciofluvial sediments have inundated the valley to depths of up to 40 or more metres. Gold-bearing gravels are currently being mined beneath this thick cover of barren overburden.

Preliminary sedimentological and stratigraphic data indicate three main lithostratigraphic assemblages: 1) Crudely stratified, imbricate boulder-cobble gravel and muddy boulder-cobble diamict; 2) Stratified cobble-pebble gravel, stratified sand and laminated silt; and 3) Stratified silt, massive boulder-cobble gravel and silty boulder diamict.

Lithostratigraphic assemblage 1 is gold-bearing and is interpreted as Reid-age subglacial or proximal glaciofluvial outwash and Reid-age proximal alpine glacial till. Gold in these sediments is concentrated either as a function of hydraulic interaction with bedrock topography, or as a result of incorporation and dispersion of a pre-existing placer deposit formed during a previous interglacial period. Lithostratigraphic assemblage 2 is interpreted as an interglacial wandering gravel bed river indicated by several fining upward sequences and wood radiocarbon dated at 32,320a. +/- 1270 B.P. (Beta-86851). Lithostratigraphic assemblage 3 is interpreted to be McConnell age glaciolacustrine silt, glaciofluvial outwash and glacial till.

The Keno Hill Silver District (United Keno Hill Mines) lies a few kilometres upstream of the placers and native silver nuggets have been recovered during present and historic placer mining. Lode sources of gold are also known to occur on nearby Mt. Hinton, which indicates the gold in the placers is likely from local bedrock sources. The ubiquitous and extensive nature of facies assemblage 2 combined with the possible existence of other hardrock sources of gold indicates that a significant potential exists for more placer gold reserves in the same drainage.

[1] Exploration and Geological Services Division, Northern Affairs Program, Yukon Region, #345-300 Main St., Whitehorse, Yukon Y1A 2B5.

Introduction

The Mayo area, although it is glaciated and not as famous as the Klondike Gold Fields, has been the site of placer gold mining from the turn of the century to the present day. Duncan Creek, a tributary of Mayo River which drains Mayo Lake, has had activity since 1902 and at one time was staked from its mouth to its headwaters (Figure 1). In 1995 only two mining operations were active, the Taylor family (Duncan Creek GoldDusters) on Duncan Creek and the Barchen family (Bardusan Placers) on Upper Duncan Creek.

Placer deposits in the Mayo area occur in a wide variety of geomorphic settings, including alluvial fans, gulch gravels, valley-bottoms (alluvial plains), and bedrock terrace (bench gravel) settings which have been variably buried and reworked by glaciofluvial processes. Placer gold is also known to occur in glacial till and glaciofluvial gravels especially where these sediment types are close to bedrock.

Previous Work

Several researchers have conducted surficial or placer-related studies in the Mayo district including H.S. Bostock (1948, 1966, 1970), who compiled the initial map of glacial limits in central Yukon, and O.L. Hughes (Hughes et al., 1969) who later expanded and added detail to this initial work. Vernon and Hughes (1966) conducted surficial mapping on adjacent map sheets 106D, 116A, 116B and 116C. A series of 1:100 000 scale surficial maps of the Mayo area was published by O.L. Hughes in 1982. C.R. Burn (1990, 1994) has been conducting permafrost and related geomorphological studies in the Mayo area since the early 1980's and his work continues to the present. A. Duk-Rodkin (Duk-Rodkin and Froese, 1995; Duk-Rodkin et al., 1995) and L.E. Jackson, Jr. of the Terrain Sciences Division, Geological Survey of Canada, have conducted recent studies of the Reid and McConnell glacial limits in the central Yukon, including Mayo. A Masters thesis detailing the Quaternary geology of the Mayo area was recently completed by T.R. Giles (1993) at the University of Alberta. The surficial geology of the adjacent McQuesten map sheet is currently the subject of a Masters thesis in geography by J. Bond at the University of Alberta (Bond, this volume). A Bachelor's thesis which examined the revegetation process on placer mine tailings was completed recently by C. Wilson at Trent University (Wilson et al., this volume).

Glacial History of Mayo Area

Three major Quaternary glaciations (the pre-Reid, Reid and McConnell, in order of oldest to most recent) and their associated interglacials have modified the drainage and topography of the Mayo area, and these events have affected the formation, preservation and proportionate size of the District's placer gold deposits.

The pre-Reid glaciations, first described by Bostock (1966) in central Yukon, are considered to by the oldest and most extensive Cordilleran ice advance. Although recent research (Duk-Rodkin et al., 1995; Bond, this volume) has shown that there are several glaciations which are pre-Reid in age, these events are often collectively referred to as the pre-Reid.

Geomorphological features of the pre-Reid ice advances are rare on the Mayo map sheet but have been recognized on the adjacent McQuesten map area (Bostock, 1966; Hughes et al., 1969; Bond, this volume). In the Clear Creek area pre-Reid glacial drift overlies gold-bearing Tertiary gravel (Morison, 1983).

The Reid glaciation, although less extensive than the pre-Reid glaciations, has left more conspicuous geomorphic evidence in the Mayo area. Meltwater channels and glaciofluvial gravels occur on ridges and saddlebacks above the main valleys in the Mayo area to elevations of up to 1280 metres (Hughes, 1982).

The McConnell glaciation, although the least extensive, has left the most prominent evidence of its advance into the area. Glacial drift of McConnell age fills most of the main valleys including the South McQuesten River, Mayo River and Keno-Ladue River. In smaller valleys into which McConnell ice did not advance, ice often blocked fluvial outflow and valleys filled with glaciofluvial and glaciolacustrine drift.

Placer Mining History

Although the Mayo District is more famous for its silver deposits, placer gold mining has taken place since the turn of the century. There are three main placer mining areas in the Mayo District: Mayo Lake/ Duncan Creek, Haggart Creek/Dublin Gulch, and Highet Creek/Minto Lake tributaries.

Duncan Creek, a tributary of the Mayo river which drains Mayo Lake, is one of the most actively-mined drainages in the Mayo District. Placer mining began in the Duncan Creek area in the early 1900's and has continued almost continuously to the present day. Gold production from Duncan Creek in the last 15 years has been nearly 20,000 crude ounces, with historical production estimated to be at least twice that for the last 95 years.

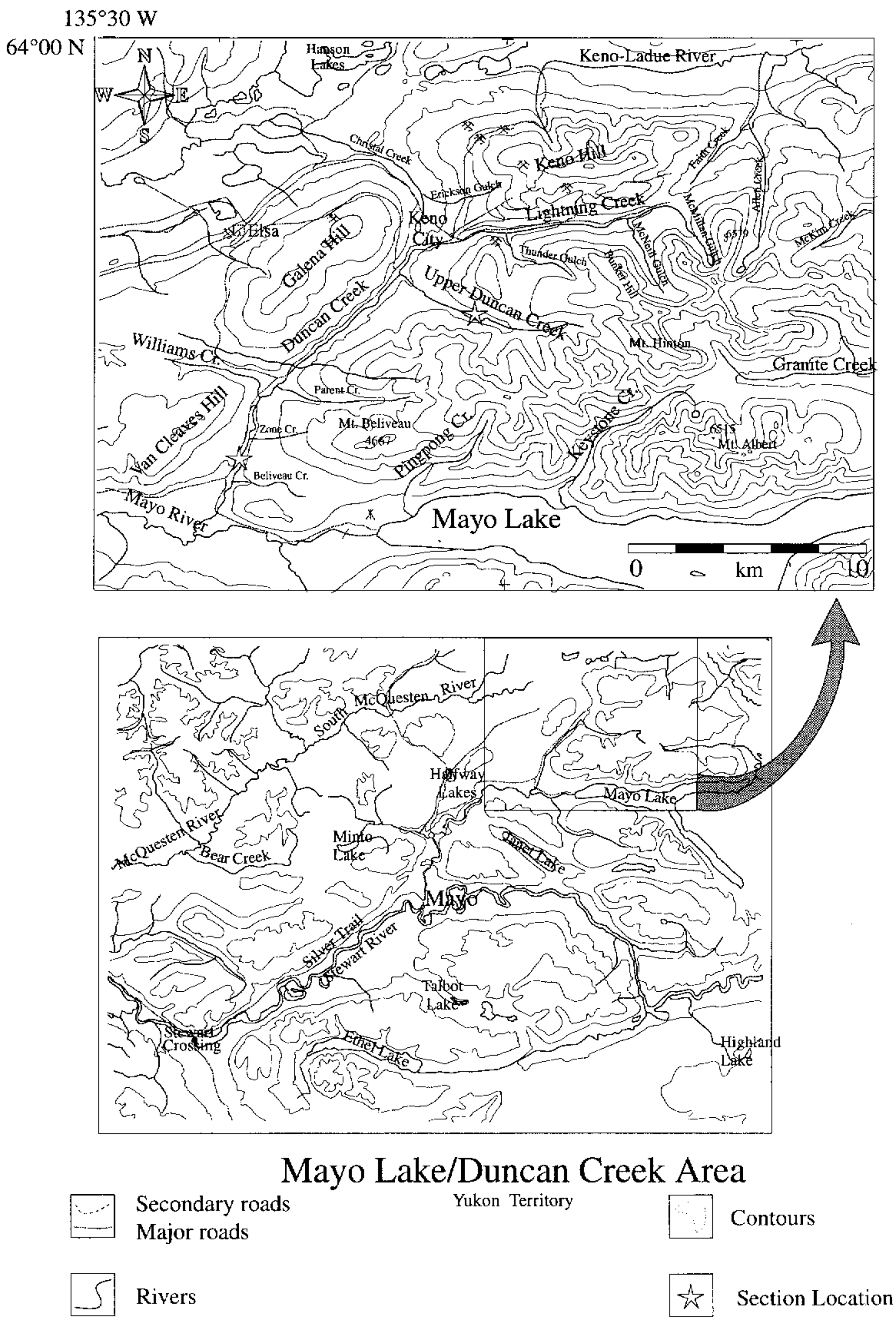


Figure 1: Section locations - Mayo/Duncan Creek area

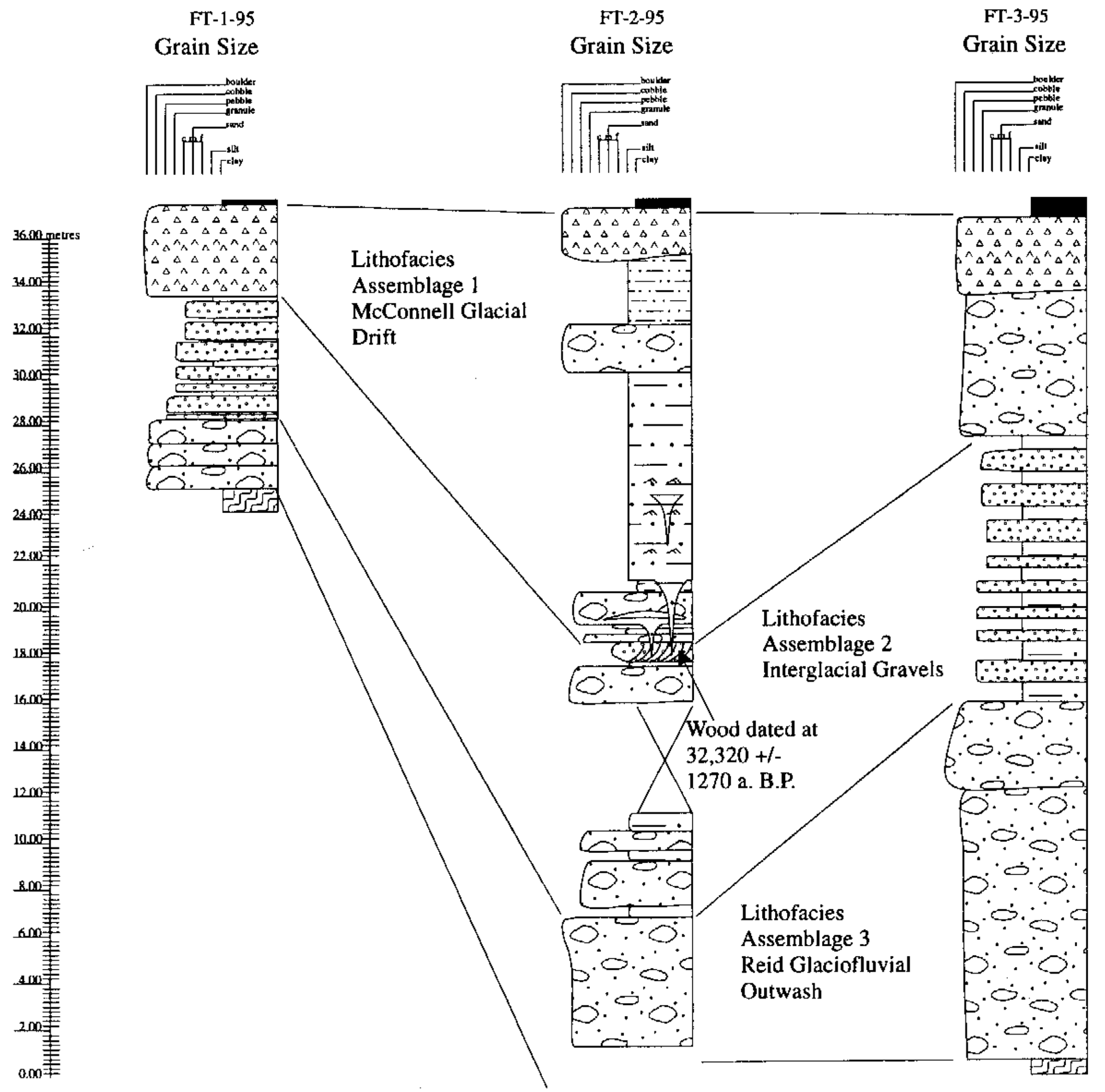


Figure 2: Sedimentology and stratigraphy of measured sections - Duncan Creek

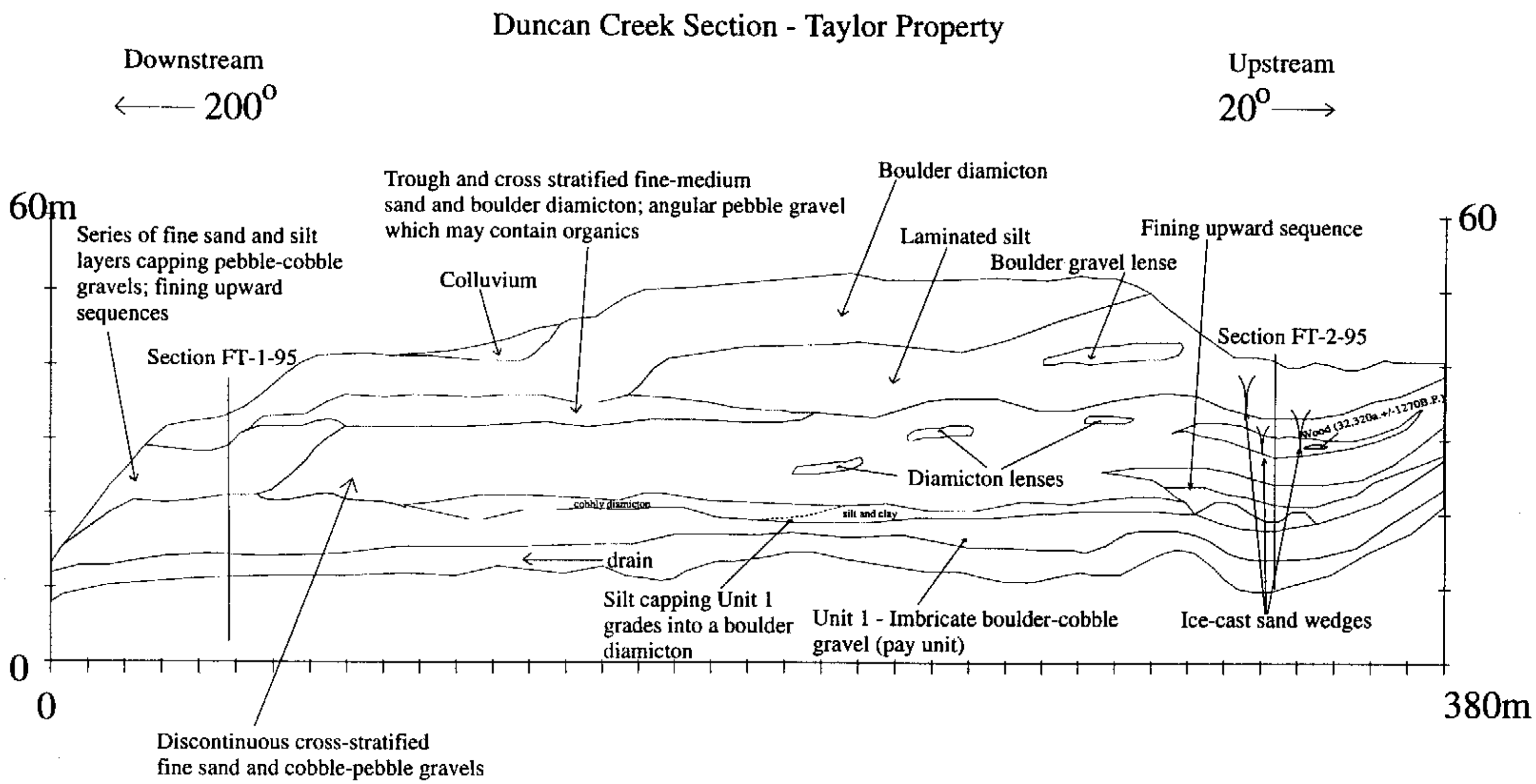


Figure 3: Cross-section of exposure on Duncan Creek showing lateral variations.

Placer Geology of the Mayo area

In the Mayo area the Reid and the McConnell glacial limits are in close proximity to one another, mainly due to variations in topography and elevation. Many of the placer gold deposits in the Mayo area lie within a zone of complex interaction between these glacial limits.

Haggart Creek and its tributaries (including Dublin Gulch) lie within the Reid glacial limits, just outside of the McConnell glacial limits. Placer deposits consist of valley bottom and gulch placers which have formed since the Reid glaciation.

Placer creeks on Mayo Lake tributaries, as well as Duncan Creek and the surrounding area, have reaches just within the margin of the McConnell glaciation but also have portions which are only within the Reid glacial limits. Most of the actively-mined Mayo Lake placer deposits lie at the apex of alluvial fans which have built into the lake since the McConnell glaciation. Placer deposits along the Duncan Creek drainage consist of valley-bottom and gulch placers as well as gold-bearing gravels which may be glaciofluvial and glacial in origin.

Fieldwork

Fieldwork for this study began in July, 1995 and will continue in the 1996 field season. Sections were measured and samples taken throughout the mining season as mining progressed and new exposures were revealed (Figure 1).

A major collaborative research project, funded through the Canada/Yukon Geoscience Office, has been proposed for the Mayo area for 1996 and part of this study will address stratigraphic problems uncovered by 1995 fieldwork.

Lithostratigraphic Assemblages

Preliminary sedimentological and stratigraphic data indicate three lithostratigraphic assemblages, which are sedimentary facies grouped on the basis of common lithology and stratigraphy. These assemblages are bounded by unconformable contacts, and they occur repeatedly throughout the study area in similar geomorphic landforms and stratigraphic position. They are as follows:

1) Crudely stratified, imbricate boulder-cobble gravel and muddy boulder-cobble diamict;
2) Stratified cobble-pebble gravel, stratified sand and laminated silt; and
3) Stratified silt, massive boulder-cobble gravel and silty boulder diamict.

Lithostratigraphic Descriptions

Lithostratigraphic Assemblage 1

Assemblage 1 consists of crudely stratified, imbricate boulder-cobble gravel and muddy boulder-cobble diamict. This assemblage occurs in the lowest stratigraphic position in contact with bedrock in all measured sections. It includes the following facies:

Facies 1 : Massive to crudely stratified imbricate boulder-cobble gravel.

This facies occurs in all sections measured on Duncan Creek (Figures 2, 3 and 4). It consists of a clast-supported boulder-cobble gravel with approximately 75-80% clasts and 20-25% matrix. Clasts are comprised of approximately 50% boulders, 30% cobbles and 20% pebbles. Crude stratification is defined by variations in clast size, with smaller boulder beds and cobble beds separated by larger boulder gravel beds. Coarsening upwards is demonstrated by an increase in clast size near the top 2-4 metres of the section. Intermediate (b-axis) imbrication is prevalent and more common near the top of the section. Clasts are subrounded to rounded with the exception of scattered boulders of angular, locally derived bedrock. Lithologies consist of local quartzite and diorite, with scattered phyllite and rare conglomerate, sandstone and limestone. Maximum clast size is 3 metres, although these boulders are rare and always rest on bedrock. The maximum bed thickness of this facies is 15 metres. As this facies is the main pay unit on Duncan Creek, accessories include heavy mineral concentrations including gold, native silver and abundant hematite. Gold concentrations occur throughout but increase in grade near bedrock.

Figure 4: Placer gold is mined from a crudely stratified, imbricate boulder-cobble gravel on Duncan Creek. Gold occurs throughout this thick gravel unit though grade increases near the bedrock contact.

Facies 2: Muddy boulder-cobble diamict

This facies occurs on bedrock in association with facies 1 on Duncan Creek and isolated on bedrock on Upper Duncan Creek. It is massive, compact, and varies from clast- to matrix-supported, depending on the percent matrix which consists of 15-25 % silt and clay. Clasts are subrounded to rounded and mainly locally-derived. Maximum particle size is 1-1.5 metres, and the maximum bed thickness is 5 metres. Accessories include gold and heavy minerals, notably on Upper Duncan Creek where gold is found in economic concentrations in this facies.

Lithostratigraphic Assemblage 2

Assemblage 2 consists of stratified cobble-pebble gravel, stratified sand and laminated silt. This assemblage occurs in the middle stratigraphic position above lithostratigraphic assemblage 1 (Figures 2 and 3). This package of sediments was observed in most sections on Duncan Creek although it was occasionally absent and assemblage 3 rested directly on assemblage 1. It includes the following facies:

Facies 3: Stratified and planar cross-stratified pebble-cobble gravel

This facies consists of clast-supported, cobble-pebble gravel with 75-80% clasts and 20-25% matrix. Planar horizontal stratification is common with occasional planar tabular cross-stratification. Units are often fining upward which is demonstrated by a rapid decrease in clast size upwards and a gradational contact with facies 4.

Facies 4: Massive and cross-stratified medium sand

This facies occurs in association with facies 3, and consists of beds of planar tabular cross-stratified fine to medium sand and occasional beds of massive medium sand. Maximum bed thickness is in the range of 0.5 metres. Accessories include woody material and organic laminations. A woody sample found within a massive medium sand was radiocarbon dated at 32,320a. +/- 1270 B.P. (Beta-86851).

Facies 5: Planar and ripple-laminated stratified silt and clay

This facies occurs in sharp contact with facies 4. Planar horizontal laminations and ripple laminations are common, and silt is more dominant near the bottom of units which are often capped by thin clay layers. Maximum bed thickness ranges up to 1 metre. Accessories include occasional organic laminations and woody material.

Lithostratigraphic Assemblage 3

Assemblage 3 consists of stratified silt, massive boulder-cobble gravel and silty boulder diamict. It is always in the upper stratigraphic position and is found at most sections measured on Duncan Creek, although it was not observed on Upper Duncan Creek. This unit often forms near vertical cliffs on natural exposures or mining cuts (Figure 5). It includes the following facies:

Figure 5: View of Duncan Creek GoldDusters mining operation in 1995. Thick glaciolacustrine silt and interstratified sand and gravel form the recessive part of the section. The resistant lower unit is comprised of a gold-bearing coarse boulder gravel.

Facies 6: Planar stratified silt

This facies consists of planar stratified, well-sorted silt with occasional intrabeds of massive sand and pebble-cobble diamict. Rare ripple laminations also occur. Maximum bed thickness is 20 metres in the sections measured, and accessories such as woody material are absent. Cryogenic features such as ice-cast sand wedges occur in the lower 3-4 metres, some of which truncate upper units of lithostratigraphic assemblage 2.

Facies 7: Massive boulder-cobble gravel

Boulder cobble-gravel of facies 7 is massive, clast- to matrix-supported and usually bounded on its upper and lower contacts by facies 6. Clasts are subrounded to rounded and a mixture of locally-derived and regionally-derived lithologies.

Facies 8: Silty boulder diamict

This coarse facies often caps lithostratigraphic assemblage 3, though occasional discontinous lenses are found within facies 6 (planar stratified silt). It consists of massive subrounded to rounded boulders with a silt to sand matrix.

Facies Interpretations and Lithostratigraphic Relationships

Facies 1, crudely stratified, imbricate boulder-cobble gravel, is interpreted to be a subglacial or proximal glaciofluvial outwash deposit. Massive, coarse gravels are typical of braid bars in proximal outwash deposits (Boothroyd and Ashley, 1975), as are crude stratification and low-angle structures (Miall, 1977, 1978; Hein and Walker , 1977). The maximum clast size of 3m implies that the deposit has either reworked a morainal deposit or was subject to extremely high discharge associated with a proximal position within a major glacial ice sheet.

Facies 2, muddy boulder-cobble diamict, is interpreted to be a lodgement till based on its compact nature, high proportion of mud matrix and association with facies 1.

Despite the common hypothesis that placer gold is not usually found in economic amounts in glacial and glaciofluvial environments (Levson and Morison, 1995), both facies 1 and 2 are gold-bearing, in economic quantities in many sections. Gold values are dispersed throughout facies 1 as would be expected in a proximal braided river system, although the highest grade is found close to bedrock. Concentrations of placer gold in facies 1 is likely the result of hydraulic concentrations in migrating bedforms and interaction with bedrock topography (Slingerland, 1984; Eyles and Kocsis, 1989). Placer gold in facies 2 may be the result of incorporation and dispersion of a pre-existing interglacial placer deposit or the result of local erosion and incorporation of a weathered or residual bedrock source of gold (Herail et al., 1989).

A Reid glacial age is hypothesized for lithostratigraphic assemblage 1 based on its stratigraphic position below assemblage 2 and 3.

Facies 3, 4 and 5 are interpreted to form as the result of migrating longitudinal channel bars (facies 3), ripple and dune bedforms on channel bar tops (facies 4) and overbank or backwater deposits (facies 5) (Harms et al., 1982). The presence of several fining upward sequences and lateral accretion deposits such as planar tabular cross-bedding indicates that lithostratigraphic assemblage 2 may be a wandering gravel bed river system (Church, 1983).

In proximal environments this type of fluvial system may resemble a braided stream environment (Desloges and Church, 1987). This may explain why the contact between facies 1 and 3, which represents the transition between a glacial outwash and a fluvial braided stream environment, is sometimes difficult to discern in measured sections (Figure 3). This stratigraphy and the presence of wood radiocarbon dated at 32,320a. +/- 1270 B.P. (Beta-86851) implies that lithostratigraphic assemblage 2 is an interglacial fluvial deposit which formed between the Reid and McConnell glaciations.

The placer gold potential of this assemblage should be significant, however in the main valley of Duncan Creek these sediments do not appear to contain much gold. It may be that since much of the valley was filled with thick, Reid-age glacial drift (where the gold is dispersed throughout except near bedrock), interglacial reworking was not enough to create significant concentrations of placer gold. This assemblage is probably a more important source of gold in tributary valleys and gulches where Reid drift is thinner and bedrock sources of gold are still available for erosion.

Cryogenic features such as ice-cast sand wedges truncate facies 3, 4 and 5, and probably occurred during climatic cooling as the McConnell glacial ice advanced into Duncan Creek valley.

Facies 6 is interpreted to be a silt deposited in a glacial lacustrine environment, due to the overall thickness of units, the presence of scattered diamict lenses (which may be ice-rafted dropstones) and its planar-stratified nature, which is a result of sediment deposition under very low flow conditions. Facies 7 is interpreted to be glaciofluvial gravel outwash, and facies 8 is interpreted to be an ice marginal meltout till. As lithostratigraphic assemblage 3 caps most sequences, it is interpreted to be ice-marginal McConnell age glacial drift.

Paleogeographic History

There is little geomorphic evidence of pre-Reid glaciations or interglacials in the Mayo map area, however it must be assumed that the long interglacial period between the end of the last pre-Reid and prior to the beginning of the Reid glaciation formed placer concentrations in Mayo area drainages. This interglacial period of at least 500,000 years would have been sufficient for fluvial systems to rework gold-bearing alluvium into significant placer deposits.

During the Reid glaciation, ice filled most valleys to elevations of at least 1280 metres, spilling outwash gravels over ridges and altering previous drainage patterns. Major valleys such as Duncan Creek hosted large glacial ice sheets, which deposited morainal drift and glaciofluvial outwash gravels. It was during the Reid that pre-existing (interglacial) placer deposits were incorporated, buried and reworked by glacial and glaciofluvial processes. This resulted in the dispersion of high grade interglacial pay gravels into large volumes of glaciofluvial sediment. During late stage glaciation, meltwater action was sufficient to rework some of the dispersed gold into higher grade concentrations near bedrock.

After the Reid glaciation, high discharge, sediment-laden glaciofluvial systems changed to non-glacial fluvial systems with lower, more constant flow rates and less sediment. This interglacial period spanned 150,000 years, which once again allowed significant reworking of valley alluvium and the formation of high-grade placer deposits.

Climatic cooling brought the McConnell glaciation to the area, although it was not as extensive as previous glaciations. Glacial ice did not progress far into many valleys including Duncan Creek, where it advanced only a few km up from the mouth. McConnell glacial ice also blocked the northern extent of Duncan Creek valley, advancing to just past its confluence with Lightning Creek. An extensive proglacial lake formed as a result of the ice-damming of the valley. Glaciolacustrine and glaciofluvial sediments inundated the valley to depths of up to 40 or more metres. In many areas along the McConnell ice margin these sediments buried pre-existing interglacial placers. Subsequent post-glacial downcutting has re-excavated buried valleys and re-exposed some of these placer deposits. Recent gulch and valley-floor placers have also formed through post-glacial fluvial reworking of gold-bearing alluvium and bedrock sources.

Placer Gold Potential

The Keno Hill Silver District (United Keno Hill Mines) lies a few kilometres upstream of the placers and native silver nuggets have been recovered during present and historic placer mining. Lode sources of gold are also known to occur on nearby Mt. Hinton, which indicates the gold in the placers is likely from local bedrock sources. Since the mineable placer deposit is likely glaciofluvial in origin and these facies are characteristically large in volume and extent, potential exists for significant additional placer gold reserves in the same drainage. In fact, similar facies have been observed in other localities within the Duncan Creek area. Further exploration, stratigraphic study and bulk testing in this area may result in the discovery of significant additional placer gold reserves.

Acknowledgements

This study could not have been possible without the generosity and hospitality of the Taylor family on Duncan Creek, who allowed the author complete access to their mining sections throughout the season and a trailer sized camping spot on their property. Geological discussions with Troy Taylor were also interesting and informative.

The Barchen family on Upper Duncan Creek are also thanked for their hospitality. Jeff Bond (University of Alberta), Fran Hein (University of Calgary) and Trevor Bremner (Geology Division, Northern Affairs) contributed useful discussions and ideas. Excellent digitization of maps and sections by Paulina Mindermann allowed the timely completion of this paper.

References

BOOTHROYD, J.C., and ASHLEY, G.M. 1975. Processes, bar morphology and sedimentary structures on braided outwash fans, northeastern Gulf of Alaska. *In*: Jopling, A.V., and McDonald, B.C. (eds), Glaciofluvial and Glaciolacustrine Sedimentation: Society of Economic Paleontologist and Mineralogists Special Publication, 23, p.193-222.

BOSTOCK, H.S. 1948. Physiography of the Canadian Cordillera, with special reference to the area north of the fifty-fifth parallel. Geological Survey of Canada, Memoir 247, 106 p.

BOSTOCK, H.S. 1966. Notes on glaciation in central Yukon Territory. Geological Survey of Canada. Paper 65-36, 18 p.

BOSTOCK, H.S. 1970. Physiographic regions of Canada. Geological Survey of Canada, Map 1254A.

BURN, C.R. 1990. Implications for Paleoenvironmental Reconstruction of Recent Ice-wedge Development at Mayo, Yukon Territory. Permafrost Periglacial Processes, 1: 3-14.

BURN, C.R. 1994. Permafrost, tectonics, and past and future regional climate change, Yukon and adjacent Northwest Territories. Canadian Journal of Earth Sciences, 31: 182-191.

CHURCH, M. 1983. Pattern of instability in a wandering gravel bed channel. *In*: J.D. Collinson and J. Lewis (eds), Modern and Ancient Fluvial Systems. International Association of Sedimentologists, Special Publication, 6, p.169-180.

DESLOGES, R.J., and CHURCH, M. 1987. Channel and floodplain facies in a wandering gravel bed river. *In*: Recent Developments in Fluvial Sedimentology. Society of Economic Paleontologists and Mineralogists, Special Publication, 39, p.99-110.

DUK-RODKIN, A., and FROESE, D. 1995. Origin and extent of drift cover, northwestern Canada. Poster presented at the Cordilleran Roundup, Vancouver, British Columbia, February 1995.

DUK-RODKIN, A., BOND, J., JACKSON, L.E. Jr.., and BARENDREGHT, R.W. 1995. Mid to Late Cenozoic record of glaciations in the northern Canadian Cordillera. Abstract and poster presented at the Cordilleran Roundup, Vancouver, British Columbia, February 1995.

EYLES, N. and KOCSIS, S.P. 1989. Sedimentological controls on gold in a late Pleistocene glacial placer deposit, Cariboo Mining District, British Columbia, Canada. Sedimentary Geology, v. 65, p. 45-68.

HARMS, J.C., SOUTHARD, J.B., and WALKER, R.G. 1982. Structures and sequences in clastic rocks, SEPM short course No. 9, Society of Economic Paleontologists and Mineralogists, Tulsa, Oklahoma, 249 p.

HEIN, F.J., and WALKER, R.G. 1977. Bar evolution and development of stratification in the gravelly braided Kicking Horse River, B.C. Canadian Journal of Earth Sciences, 14, p. 562-570.

HERAIL, G., FORNARI, M., VISCARRA, G., LAUBACHER, G., ARGOLLO, J., and MIRANDA, V. 1989. Geodynamic and gold distribution in the Tipuani-Mapiri Basin - Bolivia. International Symposium on Intermontane basins: Geology and Resources. Proceedings. pp. 342 - 352.

HUGHES, O.L., CAMPBELL, R.B., MULLER, J.E., and WHEELER, J.O. 1969. Glacial Limits and Flow Patterns, Yukon Territory, South of 65 Degrees North Latitude. Geological Survey of Canada Paper 68-34 (Report and Map 6-1968). 9 p.

HUGHES, O.L. 1982. Surficial Geology and Geomorphology, 105M SW, 105M SE, 105M NW, 105M NE. Four 1: 100 000 Scale Maps with marginal notes. Geological Survey of Canada, Maps 1982-2, 1982-3, 1982-4, and 1982-5.

LEVSON, V.M., and MORISON, S.R. 1995. Geology of placer deposits in glaciated environments. *In*: Glacial Environments- Processes, sediments and landforms, J. Menzies (ed.), Permagon Press, Oxford, U.K.

MIALL, A.D. 1977. A review of the braided river depositional environment. Earth Science Reviews, 13, p. 1-62.

MIALL, A.D. 1978. Lithofacies types and vertical profile models in braided river deposits: a summary. *In*: Miall, A.D. (ed.), Fluvial Sedimentology, Canadian Society of Petroleum Geologists, Memoir 5, P. 597-604.

MORISON, S.R. 1983. Placer deposits of Clear Creek drainage basin, 115P, central Yukon. *In*: Yukon Exploration and Geology 1983, Exploration and Geological Services Division, Northern Affairs Program, Yukon Region, p. 88-93.

SLINGERLAND, R. 1984. Role of hydraulic sorting in the origin of fluvial placers, Journal of Sedimentary Petrology, v. 54, no. 1, p. 0137-0150.

VERNON, P. and HUGHES, O.L. 1966. Surficial geology, Dawson, Larsen Creek, and Nash Creek map-areas, Yukon Territory (116B and 116C east half, 116A and 106D). Geological Survey of Canada, Bulletin 136, 25p.

USING GIS AS A METHOD OF IDENTIFYING CONTROLS ON THE DISTRIBUTION OF SEDIMENT IN THE SELWYN MOUNTAINS, YUKON TERRITORY

Valerie F. Sloan[1]

Sloan, V.F., 1996. Using GIS as a Method of Identifying Controls on the Distribution of Sediment in the Selwyn Mountains, Yukon Territory. *In*: LeBarge W.P. (ed.), 1996. Yukon Quaternary Geology Volume 1, Exploration and Geological Services Division, Northern Affairs Program, Yukon Region, p. 73-84.

Abstract

The following paper outlines a method of identifying controls on the distribution of postglacial alpine sediments in the Selwyn Mountains using a Geographic Information System (GIS) as a vehicle to analyze surficial geology maps, bedrock geology maps, and topographical data.

Postglacial alpine sediments in this region include talus, rock glaciers, alluvial fans and Neoglacial till and the spatial distribution of these sediments is controlled by factors such as lithological properties and site characteristics which in turn influence weathering and erosion. As a result, the sediment distribution may give clues about the bedrock weathering and site conditions. The method of cross tabulation is a powerful tool that can provide insight into the spatial patterns of landforms, and processes such as sediment accumulation and landscape denudation. It allows an examination of the distribution of bedrock and surficial geology units with respect to each other and to other map variables such as elevation, slope and aspect. The analysis of the spatial distribution of sediment and the calculation of rates of landscape denudation for different bedrock units then require the use of a G.I.S.

Preliminary results suggest that rates of denudation are controlled by a number of factors including bedrock type and site conditions such as elevation and aspect.

[1] Dept. of Geological Sciences and INSTAAR, Campus Box 450, University of Colorado, Boulder, CO 80309-0450
Valerie.Sloan@Colorado.Edu

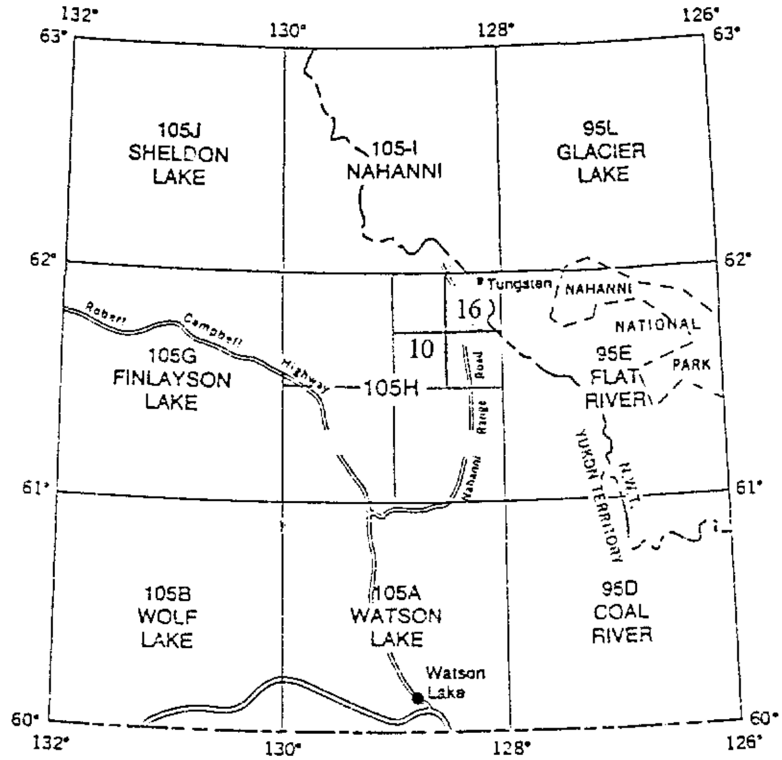


Figure 1: Location map showing study areas 105H10 (Anderson Lake) and 105H16 (Tungsten), as well as areas and names of adjoining topographic maps.

Introduction

Sediments including talus, rock glaciers, alluvial fans, and Neoglacial till (Figs. 2-4) have accumulated on the alpine slopes of the Selwyn Mountains since deglaciation (Figs.1-4, Dyke, 1990a). The region was entirely covered by the Logan Ice Dome, a northern extension of the Cordilleran Ice Sheet during the last glaciation (Dyke and Prest, 1987, Dyke, 1990a,b) and was deglaciated about 11,500 years ago, as indicated by radiocarbon dated lake sediments near Teslin (GSC-3831, McNeely and McQuaig, 1989). This provides a temporal framework for the alpine geomorphic processes that produced the sediment deposits in the Selwyn Mountains. The distribution of these sediments can then tell us about some of the controls on bedrock weathering and erosion. The method of cross-tabulation allows an examination of the distribution of bedrock and surficial geology units with respect to each other and to other map variables such as elevation, slope and aspect.

Rates of weathering and erosion of different bedrock units are of interest in terms of analyzing the geochemistry of fine-grained sediments. The signature of a geochemical anomaly from a resistant lithology could be masked by weathering products from a less resistent rock type nearby. That is, the relative rates of denudation of different bedrock units are of value in analyizing geochemical data. This paper presents a method of calculating rates of denudation and of identifying the controls on the spatial distribution of sediment in the alpine areas.

The bedrock geology map (Green, 1966), the surficial geology map (Dyke, 1990a,b) and the digital elevation model were brought into the GIS system. Slope aspect and steepness maps were derived from the digital elevation model (DEM). The surficial geology maps and bedrock geology maps were then cross-tabulated to examine how the rates of denudation or distribution of postglacial alpine sediments varied amongst bedrock geology units.

Study Area

The two 1:50,000 map areas used in this study are the Tungsten (105H16) and Anderson Lake (105H10) map sheets which are located in the northeastern quadrant of the 1:250,000 Frances Lake map sheet, 105H (Fig. 1). These maps cover an area of approximately 625 km^2. These areas were selected because they have relatively high relief, are underlain by a wide variety of bedrock types, and the digital elevation data was available for this region at a scale of 1:50,000.

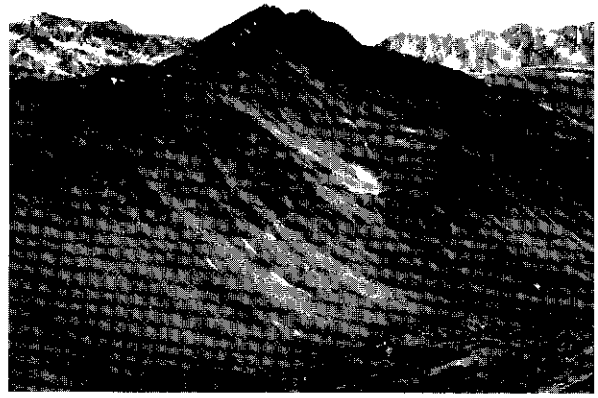


Figure 2: Talus aprons draping the alpine slopes in the Selwyn Mountains.

Bedrock Geology

The availability of the bedrock and surficial geology maps, field observations, and the use of a G.I.S, permitted the calculation of rates of postglacial mechanical denudation for five different bedrock units. Each bedrock unit consists of a number of lithologies, but can in general be classified as sedimentary, metasedimentary, metamorphic and igneous. Green et al.'s (1966) bedrock geology map provides detailed marginal notes on the lithologies, and Dyke (1990) gave a clear summary of the regional bedrock geology. The regional bedrock geology is outlined in Figure 5 and are as follows:

Table 1. Bedrock Geology

Unit 1	Metasediments: shale, slate, phyllite, conglomerate, quartzite
Unit 2	Metamorphic and igneous rocks: gneiss, schist, quartzite, small granitic bodies
Unit 3	Metasediments: slate, phyllite, siltstone, quartzite
Unit 9	Sedimentary rocks: limestone, siltstone
Unit 15	Igneous and metamorphic rocks: monzonite, granidiorite, gneiss

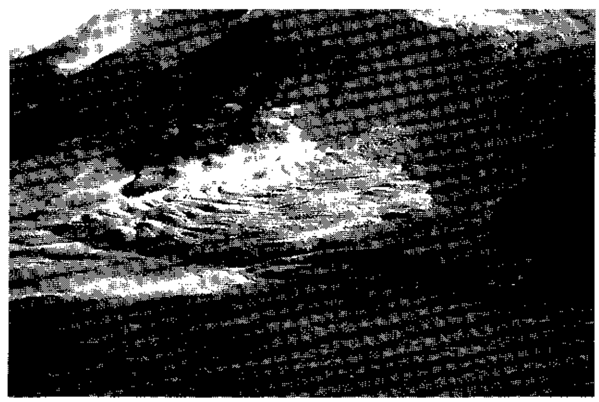


Figure 3: A rock glacier flowing over an alpine meadow in the Selwyn Mountains.

The study area covers part of the Selwyn Basin, which contains rocks ranging in age from Late Proterozoic to Cretaceous. These rocks strike northwest-southwest belts through the area. The Anderson Lake map sheet area (105H10) is underlain primarily by Late Proterozoic schist, gneiss, phyllite and quartzite, intruded by large Cretaceous batholiths consisting mostly of quartz monzonite and granodiorite (Fig. 5). The Tungsten map sheet (105H16) is underlain primarily by Lower Cambrian siltstone, shale and Cambro-Ordovician limestone and siltstone, intruded by smaller Cretaceous stocks.

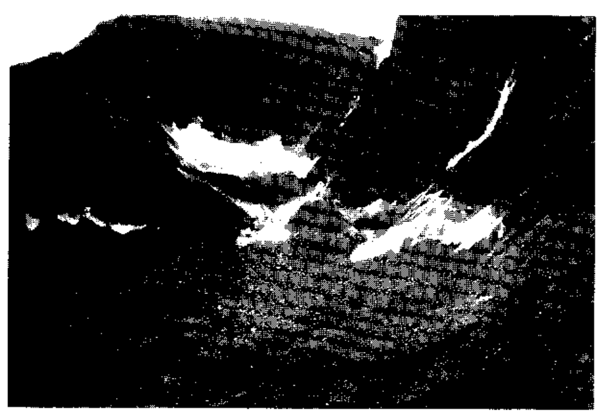


Figure 4: Neoglacial till and moraine and a small cirque glacier in the Selwyn Mountains.

Field observations in this area shows that sedimentary rocks tend to break into platy, smaller clasts, the igneous and high grade metamorphic rocks break into blocky, larger clasts and the low grade metamorphic rocks produce clasts that are intermediate in terms of platiness, blockiness and size. This suggests that sedimentary and low grade metamorphic rocks are less resistant to mechanical weathering and erosion than the high grade metamorphic or igneous rocks, and that denudation would be more rapid in those areas.

Data

Rates of denudation were calculated with data from the bedrock geology map (Green et al, 1966), the surficial materials and landforms maps (Dyke, 1990) as well as field observations made on landform and unit thicknesses. The surficial geology map and bedrock geology maps were transformed into digital formats and then cross-tabulated in a Geographic Information System. Data acquisition and transformation are described in further detail below.

Maps of the Surficial Geology

The surficial materials and landforms maps were produced through aerial photograph interpretation and field work by Dyke (1990a,b). These maps are detailed and include units and landforms such as talus aprons, alluvial fans, avalanche tracks, Neoglacial till and moraine and landslides. Units mapped on the air photos were then transferred to 1:50,000 topographic maps, and these in turn were transferred onto 1:100,000 maps (Dyke, 1990b). The unit location and unit thicknesses were verified in the field. The original 1:50,000 surficial materials and landforms maps for the Tungsten (105H16) and Anderson Lake (105H10) map units were traced onto mylar and scanned to produce a digital Autocad file. These files were imported into a G.I.S called Arc/Info where initial linework was edited and each polygon was tagged with a specific surficial geology map unit. The digital files were then imported into another G.I.S. called SPANS where further linework corrections and surficial geology classifications of the polygons was completed.

Map of the Bedrock Geology

The bedrock geology was initially mapped by Green et al. (1966) at a scale of 1:253,440. Each unit consists of lithologies that make up one or two rock types, such as sedimentary and metasedimentary rocks. The bedrock geology map for each of the Tungsten and Anderson Lake map areas was traced and scanned similar in the way the surficial geology map was done. The scanned linework was imported into Arc/Info and edited and the polygons were tagged with specific classifications. The Arc/Info files were then imported into SPANS to allow for spatial analysis.

Estimating Rates of Denudation

Accumulated sediment derived from surrounding bedrock slopes can be used as an indicator of rates of denudation (assuming that rocks undergoing weathering and erosion at more rapid rates produce larger volumes of sediment). Denudation is usually measured as landscape lowering in mm/1000 years. One can estimate rates of postglacial denudation by calculating how much landscape lowering is represented by the sediment that has accumulated in the alpine valleys. This involves determining the volume of sediment, converting it to a mass, converting the mass to a volume of rock, and finally transforming the volume into a thickness over an area that has denuded over a given length of time.

Rates of denudation for the different bedrock units are estimated here with the intent of examining variation in rates of denudation with rock type. This could also be viewed as postglacial rates of coarse-grained sediment production in the alpine environment. It is understood that fine-grained sediment is more easily transported down valley and is not accounted for here. Rates of denudation are estimated through the following sequence of steps: (1) obtaining the area of each surficial materials unit occurring within each bedrock geology unit by cross-tabulating maps in the GIS; (2) calculating a volume of material by multiplying the areas by sediment thickness; (3) determining the mass of material by multiplying the sediment volume by sediment bulk density using a value of 2000 kg/m^3; (4) converting the mass into a volume of rock by dividing by rock density (2700 kg/m^3); 5) dividing the rock volume by the area from which it was derived to get a rock thickness, and (6) dividing by a length of time to get a rate of denudation in mm/1000 years. The range of thicknesses for each surficial geology unit was obtained from field data. The relationship between surficial material and landform thickness with respect to lithology is not known, and so the same range of thickness were used for the whole map area. The most important variable is therefore the area covered by sediment.

Surficial Geology Unit		Bedrock Geology Unit* 1	2	3	9	15	Total
Rock	Area (km sq)	77.763	141.227	138.337	61.927	156.886	576.971
	% Total area	9	17	17	8	19	70
	Row %	13	24	24	11	27	
	Column %	76	79	64	60	71	
Rock plateau remnants	Area (km sq)	4.035	0.000	7.922	3.362	0.993	16.312
	% Total area	0	0	1	0	0	2
	Row %	25	0	49	21	6	
	Column %	4	0	4	3	0	
Neoglacial till	Area (km sq)	0.063	1.040	2.519	1.417	2.181	7.220
	% Total area	0	0	0	0	0	1
	Row %	1	14	35	20	30	
	Column %	0	1	1	1	1	
Talus debris	Area (km sq)	13.178	26.757	40.134	20.360	39.991	140.576
	% Total area	2	3	5	2	5	17
	Row %	9	19	29	14	28	
	Column %	13	15	19	20	18	
Rock glacier	Area (km sq)	4.542	5.156	14.956	5.234	10.179	40.068
	% Total area	1	1	2	1	1	5
	Row %	11	13	37	13	25	
	Column %	4	3	7	5	5	
Alluvial fan	Area (km sq)	2.090	3.343	4.135	3.924	5.155	18.646
	% Total area	0	0	1	0	1	2
	Row %	11	18	22	21	28	
	Column %	2	2	2	4	2	
Ice and snow	Area (km sq)	0.000	1.443	6.584	6.554	7.021	21.873
	% Total area	0	0	1	1	1	3
	Row %	0	7	31	30	32	
	Column %	0	1	3	6	3	
Total	Area (sq km)	101.671	178.966	214.857	102.778	222.406	821.666
	% Total area	12	22	26	13	27	100

***Bedrock Geology Unit**

1. quartzite,shale, slate, phyllite, conglomerate
2. gneiss, schist, quartzite, small granitic bodies
3. brown-red weathering slate, phyllite, siltstone, fine-gr. quartzite
9. argillaceous platey limestone, siltstone, fine-grained limestone
15. biotite-quartz monzonite, granidiorite, gneiss

Table 2: A cross-tabulation of the surficial geology map and the bedrock geology map for the Tungsten (105H16) and Anderson lake (105H10) 25km x 25km map areas.

Map Unit	% of sed. area	apped thick.	Min. thick.	Min. x % area	Low est. thick.	Low x % area	Med. est. thick.	Med. x % area	High. est. thick.	High. x % area	Max. thick.	Max. x % area
Talus	68.1%	1-50 m	1 m	1 m	10 m	6.81	20 m	3.62 m	30 m	0.43 m	50 m	34.1 m
Neoglacial till	3.5%	.5-20 m	0.5 m	1.75 m	5 m	.175 m	10 m	0.35 m	15 m	.525 m	20 m	0.7 m
Rock glaciers	19.4%	0-50 m	10 m	1.94 m	15 m	2.91 m	25 m	4.85 m	35 m	6.79 m	50 m	9.7 m
Alluvial fans	9.0%	2-20 m	2 m	0.18 m	5 m	0.45 m	10 m	0.9 m	15 m	1.35 m	20 m	1.8 m
Mean thickness of all sed.				4.87 m		10.35 m		19.70 m		29.07 m		46.3 m

Table 3: Mean thickness of sediment calculated by multiplying the minimum, maximum, low, medium,and high thickness of sediment by the percent of area that each unit occupies of all four units.

Area of Sediment, Bedrock Units						
	Bedrock Geology Unit					Total of
	1	2	3	9	15	bedrock area
Sediment area (km^2)	19.87	36.30	61.74	30.93	57.51	206.52
Bedrock area (km^2)	101.67	178.97	214.86	102.78	222.41	821.67
Sediment area/bedrock area	0.20	0.20	0.29	0.30	0.26	0.25

Table 4: Area of sediment in each bedrock geology unit and area of each bedrock geology unit. Includes sediment area as a proportion of bedrock area and as a proportion of total map area.

1. Cross-tabulation of Maps

In the cross-tabulation of the bedrock geology map and surficial geology map, the area of each surficial geology unit occurring in each bedrock unit was calculated. For example, the area of talus overlying each bedrock unit was calculated, along with the area of each bedrock unit underlying the talus. Table 2 shows results of the cross-tabulation of the maps of surficial geology and bedrock geology for the Tungsten (105H16) and Anderson Lake (105H10) map areas. Across the top of the table, the numbers associated with the bedrock geology units are shown: 1,2,3,9 and 15. Down the left side, the name of each surficial geology unit is shown. For example, in the fourth row and first column, we see that 13.178 km^2 of talus is found in bedrock unit 1. This represents 2% of total map area, 9% of talus area (row%) and 13% (column%) of the area underlain by bedrock unit 1. Figure 6 shows a pie chart of the relative proportion of surficial geology units making up the alpine sediments.

2. Sediment Volume

The volume of sediment was calculated by multiplying the sediment areas by a thickness. Dyke (1990b) recorded the following thickness values: talus as 0.5-50m, Neoglacial till as 0.5-20 m, rock glaciers as 10-50m and alluvial fans as 2-20 m.

In order to calculate rates of denudation, surficial geology unit thicknesses, ranging between the minimum to the maximum observed and mapped by Dyke

(1990b) were used (Table 3). Any low, medium and high values falling between Dyke's (1990b) maximum and minimum were also used. These correspond with field observations made by the author during the summers of 1994 and 1995. To get a range of sediment thicknesses representing all four alpine surficial geology units (talus, Neoglacial till, rock glaciers, alluvial fans), the percent of area occupied by each unit was multiplied by the five thicknesses (maximum to minimum) for each unit, and these are summed in Table 3. For example, talus occupies a mean of 68% of the area of sediment and is multiplied by the minimum, maximum, low, medium, and high thicknesses. This is done for each unit, and then those weighted thicknesses are added to give mean values for the minimum, maximum, low, medium, and high thicknesses. Mean thicknesses representing all four surficial geology units ranged from 2.7 m to 46.1 m for the minimum and maximum sediment thickness, and 10.3 m, 19.65 m, and 29.0 m for the low, medium, and high values.

Table 4 shows the area in each bedrock unit draped by talus, fans, Neoglacial till, and rock glaciers. It also shows the bedrock distribution area mapped of each bedrock type. The ratio of sediment area to the area mapped for by each bedrock type is presented in Table 4 as well.

Sediment volumes are calculated by multiplying the area of sediment of each unit by the mean sediment thicknesses determined in Table 3. Table 5(a) shows the results of sediment volumes in cubic meters.

3. Sediment Mass

The sediment volumes calculated in the previous section were converted to mass by multiplying the volumes by sediment bulk density. Soil or weathered material is said to have a bulk density between 1100 and 2000 kg/m^3 (Summerfield, 1991), and for the purpose of this exercise, a bulk density of 2000 kg/m^3 (Caine, pers. comm., and Davinroy, pers. comm.) was used. The results are shown in Table 5(b).

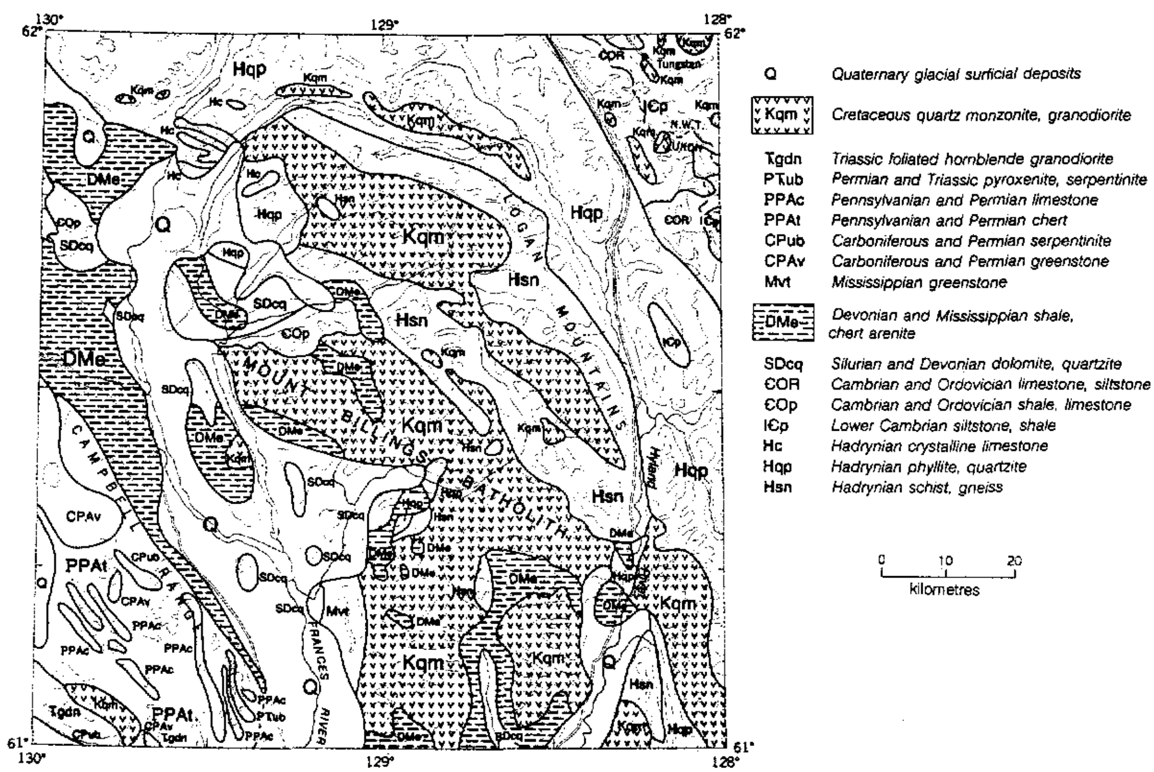


Figure 5: Bedrock geology of the Frances Lake map area (105H). The Anderson Lake and Tungsten map areas examined in this study are shown in Figure 1.

a. Volume of sediment (x $10^6 m^3$) = sed. thickness (m) x sed. area (m^2)						
Sediment thickness (m)	Bedrock geology unit 1	2	3	9	15	All bedrock units
4.87	97	177	301	151	280	1006
10.35	206	376	639	320	595	2137
19.70	391	715	1216	609	1133	4068
29.07	578	1055	1795	899	1672	6004
46.30	920	1681	2859	1432	2663	9562

b. Mass of sediment (10^3kg) = volume ($10^6 m^3$) x density (1800 kg/m^3)						
Sediment thickness (m)	Bedrock geology unit 1	2	3	9	15	All bedrock units
4.87	174	318	541	271	504	1810
10.35	370	676	1150	576	1071	3847
19.70	705	1287	2189	1097	2039	7323
29.07	1040	1899	3231	1618	3009	10806
46.30	1656	3025	5145	2578	4793	17211

c. Volume of rock eroded ($10^6 m^3$) = mass (kg)/2700 kgm^{-3}						
Sediment thickness (m)	Bedrock geology unit 1	2	3	9	15	All bedrock units
4.87	65	118	200	100	187	671
10.35	137	250	426	213	397	1425
19.70	261	477	811	406	755	2712
29.07	385	703	1197	599	1115	4002
46.30	613	1120	1906	955	1775	6375

d. Thickness of rock eroded (m) = rock vol. (m^3)/area(m^2)						
Sediment thickness (m)	Bedrock geology unit 1	2	3	9	15	All bedrock units
4.87	0.63	0.66	0.93	0.98	0.84	0.82
10.35	1.35	1.40	1.98	2.08	1.78	1.73
19.70	2.57	2.66	3.77	3.95	3.40	3.30
29.07	3.79	3.93	5.57	5.83	5.01	4.87
46.30	6.03	6.26	8.87	9.29	7.98	7.76

e. Denudation rate (mm/1000 yrs) = rock thickness (mm)/11.5						
Sediment thickness (m)	Bedrock geology unit 1	2	3	9	15	All bedrock units
4.87	55	57	81	85	73	71
10.35	117	122	172	181	155	151
19.70	223	232	328	344	295	287
29.07	329	342	484	507	436	424
46.30	525	544	771	808	694	675

Table 5: a. Volume of sediment for each bedock area calculated using different thickensses of sediment, b. equivalent mass of sediment, c. volume of rock eroded, d. thickness of rock eroded, e. rate of landscape denudation over the last 11,500 yrs.

4. Rock Volume

The accumulated sediment is made up primarily of bedrock clasts and appears to have been derived largely from bedrock outcrops. The density of the original material was therefore assumed to be that of rock, 2700 kg/m^3. By dividing the mass by the density of rock (2700 kg/m^3), the volume of rock originally eroded was determined. The results are shown in Table 5(c).

5. Thickness of Denuded Rock

These rock volumes are hypothetically "spread" over the areas underlain by each bedrock unit to give a thickness of material removed by weathering and erosion (Table 5(d)). For example, using the medium thickness, 811 x 10^6 m^3 of rock has accumulated on and therefore denuded from bedrock unit 3 (See Table 5(c)). Spread over an area of 214.86 km^2 (Unit 3, Table 4), the thickness of rock denuded is 3.77 m. If rates were to be compared with other regional or global rates of denudation, one would "spread" all of the sediments over the whole map area; however, in this case, the area of bedrock units are being compared, and so the sediment thicknesses are derived for the bedrock areas.

6. Rate of Denudation

The thickness of rock denuded determined above is divided by time to give a denudation rate of mm per 1000 years (See Table 5(e)). For example, 3.77 m of rock was denuded within the boundaries of unit 3 over approximately 11,500 years, at a rate of 328 mm/1000 years.

Accuracy and Impacts on Results

The accuracy of these calculated denudation rates depends on the data quality of the area, unit thickness, and bulk density used in this exercise. If the bulk density of the unconsolidated material is actually 1500 kg/m^3 rather than 2000 kg/m^3, the rates of denudation would be reduced by 25%. If the material originally eroded was actually a combination of bedrock and unconsolidated sediment rather than bedrock, and had a bulk density lower than rock, e.g. 2300 kg/m^3, the rates of denudation would increase by about 12.5%.

The mapping of the surficial geology was done from air photos and field work (Dyke, 1990) and the polygons were traced from the original 1:50,000 maps. It is the detail of the surficial geology maps which actually makes this analysis possible, and so the tracing or mapping are the main sources of error. On the bedrock geology map, however, as most of the units outcrop in large areas there is less room for error in mapping.

The two cross-tabulated maps are at different scales:one map scale is 1:50,000 and the other is 1:253,440. It is preferable to have maps of the same scale in such an analysis. It is possible that bedrock geology information not recorded on a map with a scale of 1:253,440 scale can affect the analysis. However, if one were to simplify the 1:50,000 surficial geology maps to a scale of 1:253,440, several polygons representing landforms such as rock glaciers or alluvial fans would be lost in the generalization.

A range of surficial geology unit thicknesses is provided to account for different possibilities. Although the resulting denudation rates vary considerably between the maximum and minimum values of sediment thickness, the low, medium, and high values of thickness cover a smaller range of denudation rates. Field observations suggest that the average thickness of these units lies between the "low" and "high" values of thickness given in Table 3, with the "medium" value representing the best estimate. The thickness of landforms was observed to vary among lithologies. Rock producing smaller, platier clasts (such as shale and limestone) develops thinner landforms than rock that produces large, blocky clasts (such as quartz monzonite and granidiorite). Further data needs to be gathered before generalizations can be made about landform thickness variation with lithology. This could potentially affect the volume calculations significantly enough to alter denudation rates of bedrock units.

Obviously the sediment did not erode from the landscape uniformly. Erosion is greater on cliffs and in cirques and lower on remnant rock plateau surfaces that are sometimes covered with blockfields. Rates of denudation calculated for other parts of the world assume uniform landscape lowering so that rates can be compared regionally. Here the rates of denudation are calculated for each bedrock area in the alpine environment so that rates can be compared.

Rates of Denudation of Bedrock Units

The rates of denudation calculated for each bedrock unit given different sediment thicknesses are shown in Figure 7. It is clear that according to this approach, the rates of denudation differ substantially amongst bedrock units. The rates of denudation calculated for unit 3 are about 50% greater than for units 1 and 2. This reflects the difference in sediment area overlying these bedrock units, shown as "sediment area/bedrock area" in Table 4, because the sediment thickness utilized in the denudation calculations was the same for each bedrock unit. It is acknowledged that the lack of data on the variation of thickness with lithology introduces uncertainty in these calculations and this exercise is intended to examine the data that are available.

The bedrock units can be classified into general groups as follows: sedimentary (unit 9), metasedimentary rocks (units 1, 3), other metamorphic rocks (unit 2), and igneous and metamorphic rocks (unit 15). It is interesting to see how the denudation rates vary with rock type. Unit 9, consisting of sedimentary rocks, has the highest calculated rate of denudation resulting from the largest area of sediment occurring per unit area (Fig. 7). Units 3 and 1, both consisting of metasedimentary rocks, have the second-highest and the lowest rates of denudation, respectively. Units 1 and 3 both include slate, phyllite, and quartzite, and one might expect them to behave similarly in terms of weathering, and yet the rates calculated for them differ by 45%.

Several possibilities exist for explaining the differences in rates of denudation for bedrock units consisting of similar lithologies. The spatial distribution and location of lithologies within each bedrock unit may differ between units, and the individual physical and chemical characteristics of the lithologies also vary. This is difficult to assess without a more detailed geologic map, and it is here that the issue of map scale becomes important.

Site characteristics of each bedrock unit may also play an important role in influencing denudation and sediment accumulation. For example, we would expect bedrock units exposed at higher elevations to produce more sediment based on higher rates of denudation. However, this is offset by the fact that more resistant lithologies frequently form the higher massifs. Weathering should intensify at higher altitudes where temperature fluctuations, wind speed, and moisture increase.

The analysis confirmed that a significant correlation exists (at the 0.05 level of confidence) between the percent area of talus occurring in each bedrock unit (talus representing 68% of alpine sediments) and the percent of area of ice and snow using one data point for each bedrock unit. Similarly, a statistically significant correlation exists between percent area of talus and percent area of Neoglacial till. These expected correlations would be based on the association of alpine glaciers, snow slopes and high mountain cirques; but they demonstrate the use of the methodology.

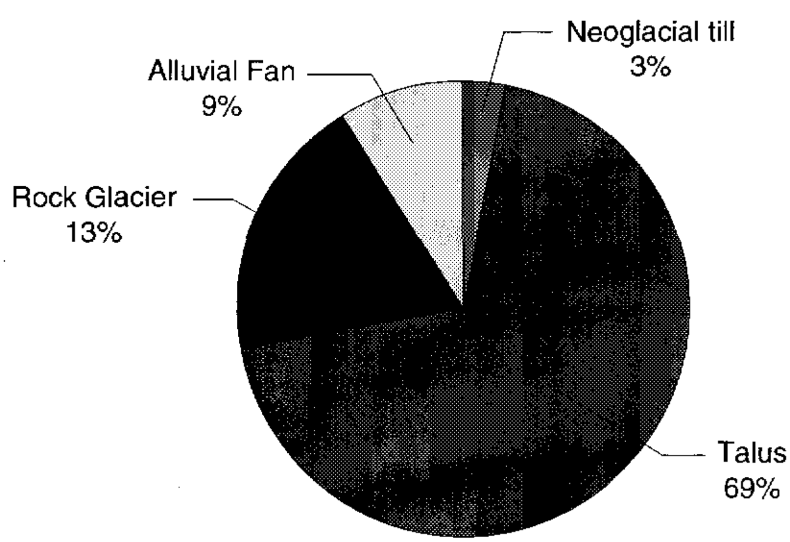


Figure 6: Relative proportions of area of each sediment type.

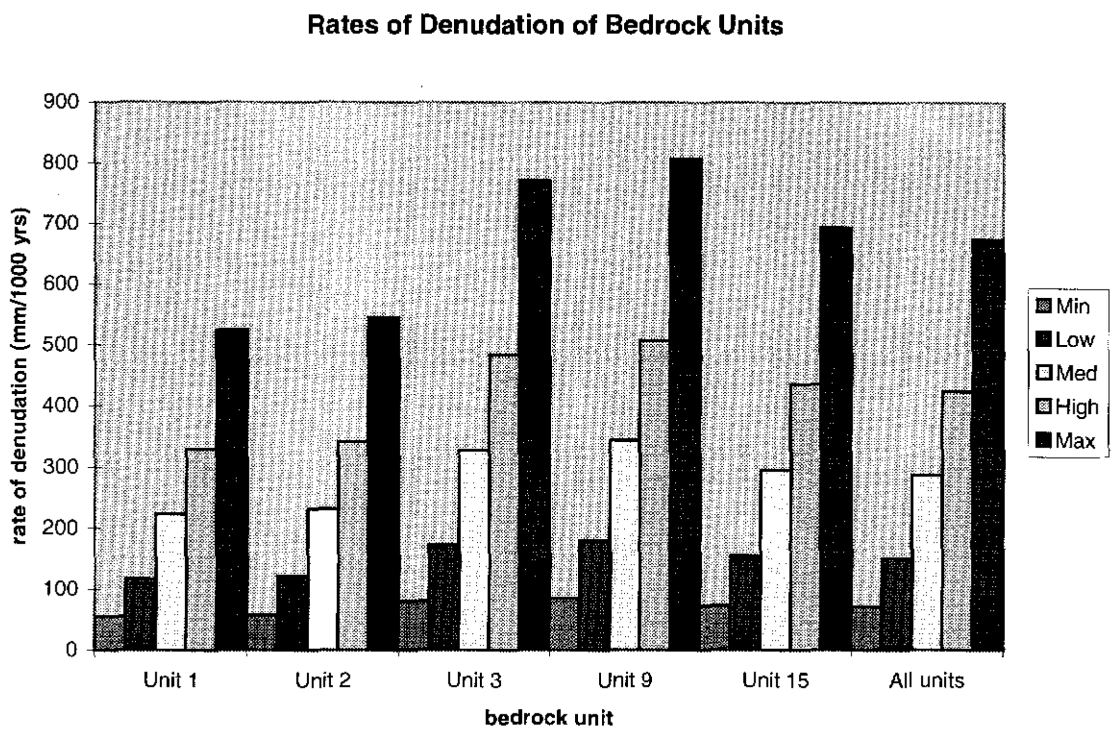


Figure 7: Rates of denudation for each bedrock unit calculated using the minimum, low, medium, high, and maximum thickness of sediment. Data is taken from table 5(e).

Future Work

Future work should investigate the site conditions of the bedrock units. A proposed plan is to cross-tabulate the bedrock geology map with the digital elevation model (DEM), and maps of slope and aspect to identify the site characteristics of each bedrock unit, to determine if the more rapidly denuding bedrock units outcrop at higher elevations than the less rapidly denuding bedrock units.

The distribution of the postglacial alpine sediments such as Neoglacial till, rock glaciers and alluvial fans with elevation, slope and aspect are also of interest. Given that cirque glaciers are more common on northeast-facing slopes, it might follow that Neoglacial till and rock glaciers (which involve snow and ice processes) are more abundant on northeast-facing slopes. A bedrock unit which strikes northwest-southeast will have more northeasr-facing slopes and therefore greater sediment accumulation resulting from nivial and glacial processes. Site conditions may therefore be significant in controlling the distribution of sediment in alpine environments. The cross-tabulation of digital maps within the GIS will permit a more in depth look at these controls on sediment distribution and bedrock weathering and erosion.

Talus occupies 68% of the area of sediments being examined. A digital map of talus source areas would identifiy slope characteristics of talus-producing versus non-talus-producing slopes, between bedrock weathering and erosion.. This should be done for all available digital maps, such as maps of slope, aspect, elevation, or bedrock geology. Once the probabilities are determined, the maps are converted to maps consisting of areas of high and low probability. These maps are then weighted according to probability statistics, and summed. The product is a probability map that shows the areas of high probability of talus-producing slopes. The characteristics of these slopes can be determined by probability statistics and can be differentiated from non-talus-producing slopes. These results may provide valuable insight into what controls bedrock weathering and erosion.

Summary

In summary, the relationship between bedrock type and rate of denudation is a complex one. For example, it is not clear that from this study metasedimentary rocks denude more rapidly than igneous rocks in this area.. The lack of data on landform thickness with lithology introduces further error and uncertainty. More bedrock mapping would be required to accurately assess the effect of lithologically controlled differences in weathering characteristics.

It appears that topographic characteristics that influence climate conditions and therefore bedrock weathering, such as elevation and aspect, may be important in controlling rates of denudation. A significant relationship was identified between percent area of talus and percent area of ice, snow, and Neoglacial till.

A cross-tabulation of the bedrock geology map and the digital elevation map is proposed to identify the altitudinal distribution of the bedrock units. The distribution of bedrock units with aspect and slope would also provide insight into controls on denudational processes. A bedrock structure with more northeast-facing slopes would provide more sites suitable for nivial and glacial processes, thereby enhancing bedrock weathering and erosion.

The cross-tabulation of maps in a G.I.S is a powerful means of examining the distribution of sediments with site characteristics. If the areas of interest are identified on a map, such as talus-producing-slopes, site characteristics which describe them can be determined using probability analysis methods. Further analyses including cross-tabulation and probability analysis are required to more clearly identify controls on the spatial distribution of sediment in the Selwyn Mountains of the Yukon Territory.

Acknowledgments

I gratefully acknowledge the support of the Northern Research Institute and the Department of Indian and Northern Affairs for financial support of fieldwork during the summer of 1995. The Geological Survey of Canada and the Department of Indian and Northern Affairs kindly provided field equipment during the summers of 1994 and 1995. The University of Colorado provided financial support in 1994 and 1995, and the American Alpine Club provided financial support in 1995. Much of this work was done under the auspices of the Geological Survey of Canada and the support is very much appreciated. Technical support was provided by André Prégent, Gary Labelle, and Richard Laframboise of the Geological Survey of Canada and is greatly appreciated. Cathy Rigg and Julia Szucs provided excellent company and field assistance under difficult circumstances and are thanked for their help. Conversations with Dr. A.S. Dyke and Dr. N. Caine also proved invaluable.

References

DYKE, A.S. 1990a. Quaternary geology of the Frances Lake map area, Yukon and Northwest Territories. Geological Survey of Canada, Memoir 426.

DYKE, A.S. 1990b. Surficial materials and landforms, Dolly Varden Creek, Yukon Territory. Geological Survey of Canada, Map 1677 A, scale 1:100,000,000.

DYKE, A.S. 1990c. A lichenometric study of Holocene rock glaciers and Neoglacial moraines, Frances Lake map area, southeastern Yukon Territory and Northwest Territories. Geological Survey of Canada, Bulletin 394.

DYKE, A. S. and PREST, V.K. 1987. Late Wisconsinan and Holocene Retreat of the Laurentide Ice Sheet. Geological Survey of Canada, Map 1702A, scale 1:5,000,000.

DAVINROY, T. at the University of Colorado, 1996, personal communication.

GABRIELSE, H., TEMPLEMAN-KLUIT, D.J., BLUSSON, S.L., and CAMPBELL, R.B. 1980. MacMillan River, Yukon-District of Mackenzie-Alaska. 1:1,000,000 Geological Atlas. Geological Survey of Canada, Map 1398A.

GREEN, L.H., RODDICK, J.A., and BLUSSON, S.L. 1966. Geology, Frances Lake, Yukon Territory and District of Mackenzie. Geological Survey of Canada, Map 6-1966, scale 1:253,440.

MCNEELY, R. and MCQUAIG, S. 1989. Geological Survey of Canada Radiocarbon Dates XXIX. Geological Survey of Canada Paper 89-7.